# HEALTH IMPACTS OF ULTRAFINE PARTICLES

## Notes of Workshop

**15 September 2020**

**David Raper and Fiona Rajé**

**CATE Manchester Metropolitan University**

AVIATOR has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814801; RAPTOR has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 863969; TUBE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814978

## 1 Workshop Objectives

This session set out to achieve the following objectives:

1. To bring together the various groups and communities
2. To share information from the various projects
3. To acknowledge knowledge gaps
4. To plan or see whether it would be useful to arrange future conversations

## 2 Attendance and format

Over 20 people from across the UFP measurement and health impact communities were invited to a workshop to hear about current research, give views about how cross-disciplinary activity might develop and enable participants to make links with other attendees.
The event was 3 hours long and held via Zoom. It was attended by 25 people, representing the TUBE, RAPTOR and AVIATOR projects and from different organisations and countries in Europe, Scandinavia and North America.
Notes of the discussion were taken and these have been collated here. They are not intended to be a verbatim record of the event but help to give a flavour of the discussions, concerns and key issues raised by people taking part in the workshop.

## 3 Workshop

### 3.1 Introduction

Dave Raper welcomed participants, explained that the workshop had been arranged to bring together those who measure with those who look at health impacts and provided an overview of the topics to be covered.

This was followed by brief introductions by each attendee.

### 3.2 Presentations and discussion

The first four presentations related to the AVIATOR and RAPTOR projects, and covered the following topics:

- Engine exit emissions – Mark Johnson (Rolls Royce)
  Mark gave an overview of his work on WP2 of AVIATOR. He noted that some work had been put back because of the current pandemic situation. Ulla asked if she could have access to a sample for in vivo particle testing. Mark agreed that this could be looked into.

- On wing measurements – Prem Lobo (NRC – Canada)
  Delivered an introduction to the different types of aircraft PM emissions, adding that PMs vary as a function of engine type, engine operating condition, fuel composition, sampling location etc. Prem went on to describe AVIATOR WP3 which looks at on-wing engine and APU emission measurements, and will explore diurnal variations. During discussion, the value of both non-volatile and volatile particle measurement

was highlighted, especially downwind as the volatiles have tended to be considered, when the solids are the ones with greater health effects. There is a new requirement from the EU for measurement of black carbon from diesel engines and this was considered to be an important substance for measurement going forwards. Prem also pointed out the importance of sharing knowledge between the 3 projects.

- Airport Ambient measurements – Dogushan Kilic (Uni of Manchester)
  Dosh introduced AVIATOR WP4 which is currently delayed by the pandemic. The main research is around 'How does the aircraft plume chemically evolve while sampling point is moving away from the runway?', 'How do climatic conditions affect the aircraft plume?' and 'What is the SOA formation potential for varying alternative fuels?' WP4 looks at ambient measurements and sensor network development, using 15-20 nodes around Madrid-Barajas airport and a reduced network at CPN and ZRH. Kevin remarked that they have been doing similar work and have been in the field for around 18 months. He suggested a joint look at data from his project and AVIATOR would be desirable.

- EMPA measurement/ lung cell impacts – Lukas Durdina (ZHAW - Switzerland)
  This presentation looked at the acute response of human bronchial epithelial cells exposed for 1hr to nvPM in engine thrust using Jet A1 fuel and alternatives (HEFA 32% blend). Acute toxicity and oxidative stress were highest at idle with Jet A1. Number and mass concentrations seem not to be primary drivers of cytotoxicity and oxidative stress. Described more to be done: different types of cells; volatile PM further downstream of engine exit; don't know if organics, sulphates, oil are more toxic, although soot particles carry these toxins. Open for collaboration at facility in Zurich. Hope to get back to testing next year.

These were followed by an introduction to the TUBE project:

- Overview of TUBE – Aims/objectives/data needs – Pasi Jalava (UEF - Finland)
  This research looks at effects of UFP from road traffic and marine engines on brain health, including disease mechanisms, translocation and clearance. Also, would like to include aviation emissions. Work is focused on Alzeimers disease. WP1 – effect of exhaust fuel aromatics on health. WP2 – work on rats. WPs3+4 – main novelty of project: cell cultures of nasal epithelial cells; how particles enter the brain/how they are cleared from the brain. WP5 – cohort of human volunteers in Sweden and China. WP6 – risk assessment, interventions and traffic policy. Overall progress: UFP samples collected for cell and animal experiments, other sample collections will continue but the pandemic has affected this/adjustments being made to allow continuation.

The final presentation related to the health impacts of emissions:

- Health effects of Airport Emissions – Ulla Vogel (NRCWE – Denmark)
  Has live in vivo data library for over 90 nano-materials. Looking at association between particulate air pollution and mortality (i.e. PM2.5 & death). Jet fuel contains fractions of gasoline and diesel - diesel engine exhaust is classified as carcinogenic to humans by IARC; gasoline engine exhaust is classified as possibly carcinogenic and black carbon is also classified as possibly carcinogenic to humans. Animal studies performed with particles collected at a non-commercial airfield and at a large commercial airport. The particles from the non-commercial airfield were almost

exclusively aggregates of nanosized carbon-based particles. The particulate matter from the commercial airports was more complex. Animal study undertaken of health effects following lung exposure to airport emissions: looked at lung histology, inflammation, acute phase response, DNA damage. Exposure to the particles caused DNA damage, inflammation and acute phase response. Aircraft emission particles have similar health effects as diesel exhaust particles which were included in the experiment as reference materials.

After the various talks, Dave thanked all for their participation and, in particular, presenters for their very informative and interesting talks. He reflected on the fact that a debate had been started that would hopefully go on after. He then turned to the objectives which he had previously described and discussed whether they had been achieved:

1. To bring together the various groups and communities – it was felt that this had been achieved successfully through links being made in conversations and in the chat box

2. To share information from the various projects – this had also been achieved through sharing from TUBE to AVIATOR and to the work being done in the USA. Although there had not been a presentation on RAPTOR work that was something that could be done later to share the interesting work to come out of that project.

3. To recognise knowledge gaps – this had been started in the conversations around those who collect particles and, likewise, it was hoped that those who do the impact assessments had begun to understand what the people who measure do and why they are trying to do it.

4. To plan or see whether it would be useful to arrange future conversations – Dave felt this would be a good idea and asked colleagues to comment. Participants stated that they had found the session very useful; it had been helpful for people to make contacts; was a welcome forum for sharing knowledge and identifying gaps and that they would like to hear more about work, for example, in the US. There was also positive comment on the simplicity of the format, lack of technical difficulties in joining and the 3-hour length of the session.

The workshop finished at 1700 (CET).

## Health Impacts of UFP – workshop

15th September 2020 14:00 (CET)

# AGENDA

1) Introduction and Welcome

**AVIATOR/RAPTOR**

2) Engine exit emissions – Mark Johnson (Rolls Royce)
3) On wing measurements – Prem Lobo (NRC – Canada)
4) Airport Ambient measurements - Paul Williams (Uni of Manchester)
5) EMPA measurement/ lung cell impacts – Lukas Durdina (ZHAW - Switzerland)

**TUBE**

6) Overview of TUBE – Aims/objectives/data needs – Pasi Jalava (UEF - Finland)
7) Health effects of Airport Emissions – Ulla Vogel (NRCWE – Denmark)

8) Discussion
9) Close 17:00 (latest)

**PARTICIPANTS**

Pasi Jalava, University of East Finland
Ulla Vogel, National Research Centre for the Working Environment, Denmark
Mark Johnson, Rolls Royce
Dogushan Kilic, University of Manchester
Ulf Janicke, Janicke Consulting
Victor Archilla, INTA
Prem Lobo, National Research Council Canada
Lukas Durdina, Zurich University of Applied Sciences
David Raper, Manchester Met University
Daniel Jacobs, USA FAA
Theo Rindlisbacher, FOCA
Spirig Curdin, Zurich University of Applied Sciences
Bethan Owen, Manchester Met University
Sanja Potgieter-Vermaak, Manchester Met University
Simon Christie, Manchester Met University

Ayce Celikel, ENVISA
Kevin Lane, Boston University
Sarav Arunachalam, University of North Carolina
Jeetendra Upadhyay, USA FAA
Mohammed Majeed, USA FAA
Richard Ramaroson, ENVISA
Paivi Aakko-Saksa, VTT Technical Research Centre of Finland
Remco Westerink, Utrecht University
Fiona Rajé, Manchester Met Uni

**UNABLE TO ATTEND**

Miriam Gerlofs-Niijland, RIVM
Andrew Crayford, Cardiff University
Paul I Williams, University of Manchester
Flemming Cassee, RIVM
Roel Schins, Leibniz Research Institute for Environmental Medicine

AVIATOR

Assessing aViaton emission Impact on local Air quality at airports: TOwards Regulation

# WP2 Test-cell engine exit and in-stack plume measurements

Health Impact UFP workshop - 15th September 2020, Virtual

Mark Johnson (Rolls-Royce Emissions Measurement Expert)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814801

# Advisory info - A1. Improved Measurement Systems for Aircraft Engine Emissions (WP2, WP3, WP4)

- Currently aircraft main engine emissions are regulated for gaseous EI's (CO, NOx, UHC's) and Smoke Number with the requirement to also report EI nvPM (mass and number) as measured within half a nozzle diameter of the engine exit.
- Engine manufacturers perform emission certification measurements within certified test-cells using the methodologies prescribed in ICAO Annex 16 Vol II.
- With the exception of the non-discriminating UHC EI concentration, neither volatile PM or gaseous precursors emitted from either the main engine core or oil breather are currently regulated. However, these pollutants will develop into species within the plume that could likely impact local air quality and health.
- At present it is therefore unknown whether current regulatory measurements are sufficiently robust in predicting the downstream concentrations of these pollutants that impact local air quality.



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# WP2 (Engine testbed work package) Rationale:

**Development of traceable, high-fidelity measurement approaches to understand total and precursor PM emission concentrations in a certified test-cell aircraft engine exit and in exhaust stack** and for on-wing testing and ambient airport measurements (WP3 & WP4)

**This work will help provide a better understanding of the potential for in-stack measurements to be used in future regulatory purposes**



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# Task 2.1 Measurement systems and sampling protocol development

- Various sampling and measurement strategies will be developed to take measurements at **engine exit, oil breather and in-stack**.
- Sampling from engine exit, will utilise a 'proven' permanently installed ETP (emissions traversable probe) at INTA.
- In-stack (50 m downstream of engine exit) measurements of the plume will be sampled using relatively shorter sampling lines to limit losses of small nucleated particles with dilution methodologies developed specific to the measurement techniques employed.
- Two high-fidelity measurement systems (baseline and dedicated) will be developed to be consistent across all dedicated measurement campaigns (WP2 and 3).
  - ***Highest (modelling) priority*** particle number concentration (speciating between nvPM and vPM) & total-PM size = Baseline system. Will be employed throughout all piggyback, dedicated and ambient air measurement campaigns (WP2, 3 and 4) to allow comparability. To facilitate comprehensive comparable measurements between WP2, 3 and 4, increase the operational efficiency and reduce risk, a bespoke AVIATOR semi-mobile laboratory will be designed and built.



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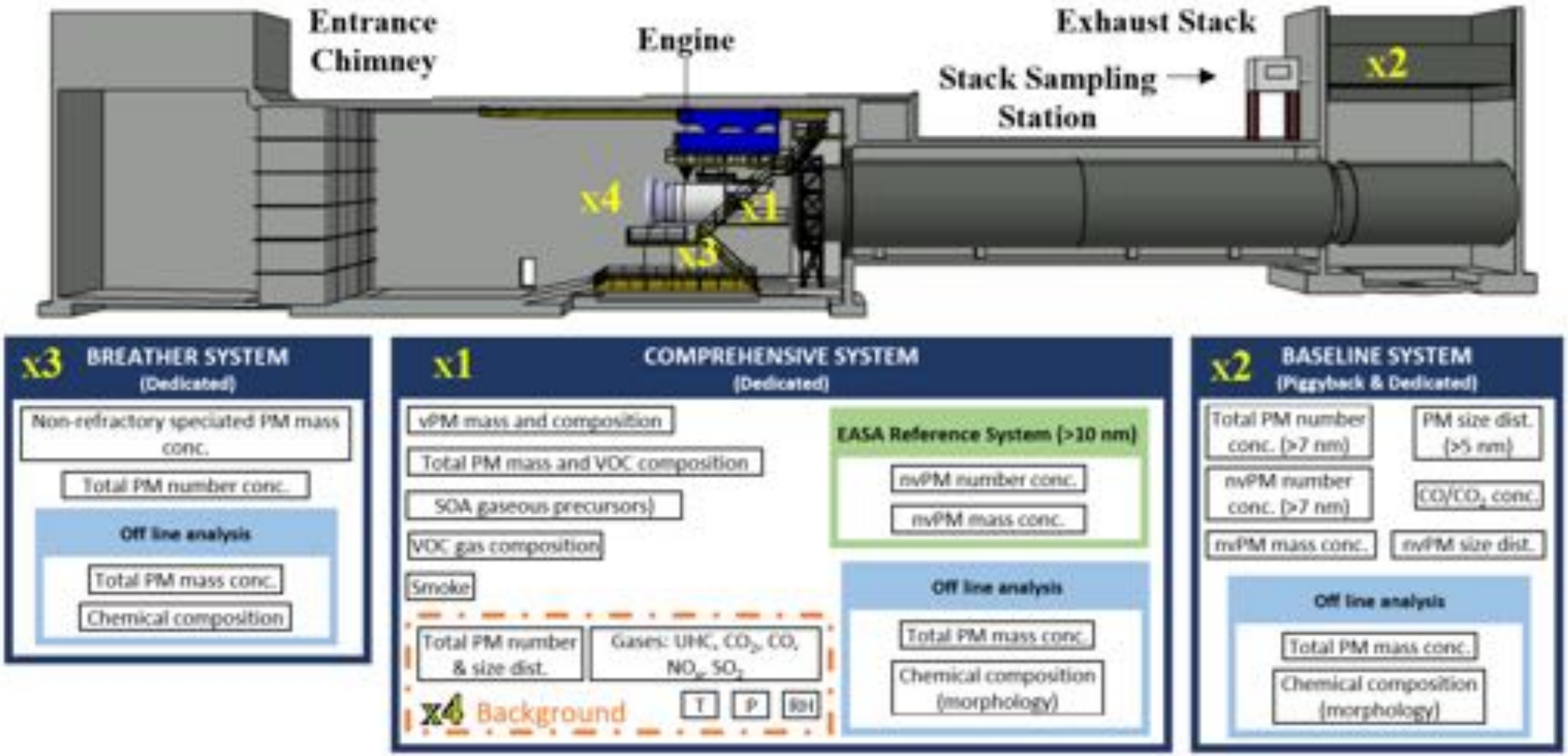
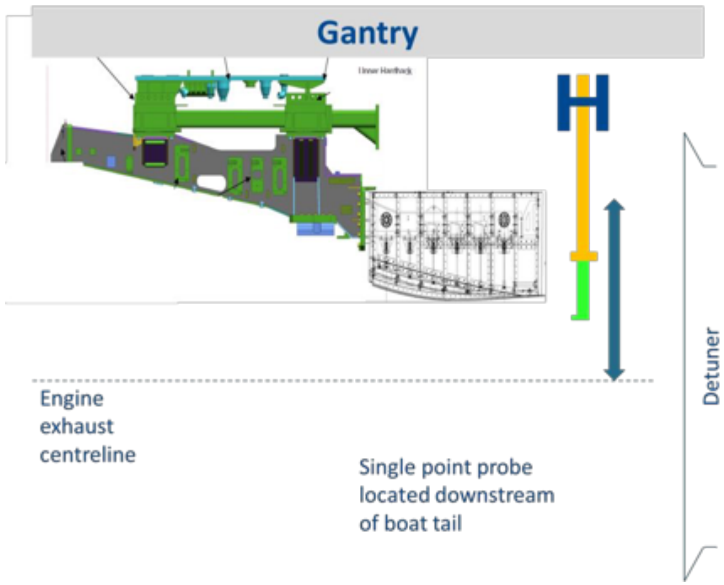
# Test-cell engine emission measurement schematic – different systems



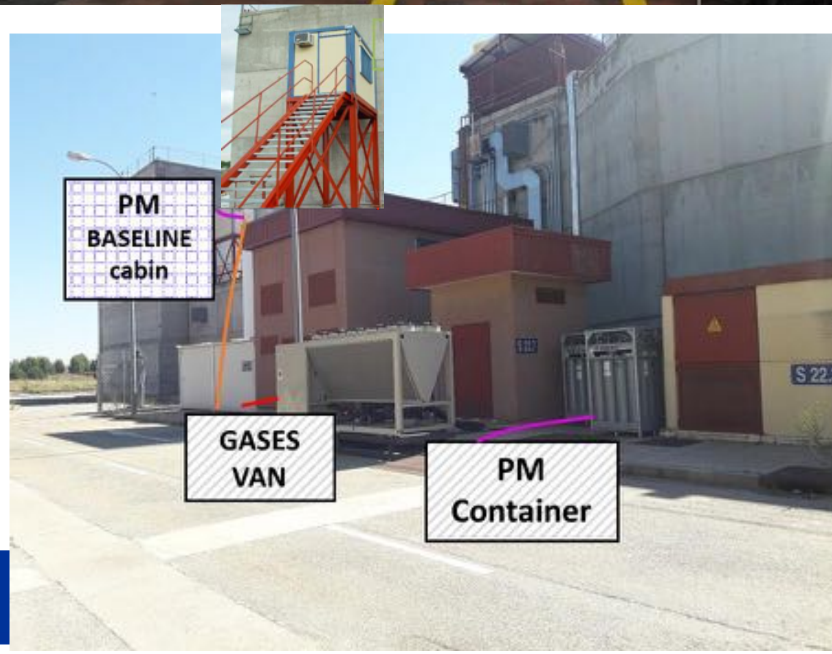

Heal

# Test-cell sampling/ location




Example EASA nvPM system setup from SAMPLEIII (SR Technics)

**Sampling conditioning**
Long (25m) heated sampling lines)
Dilution

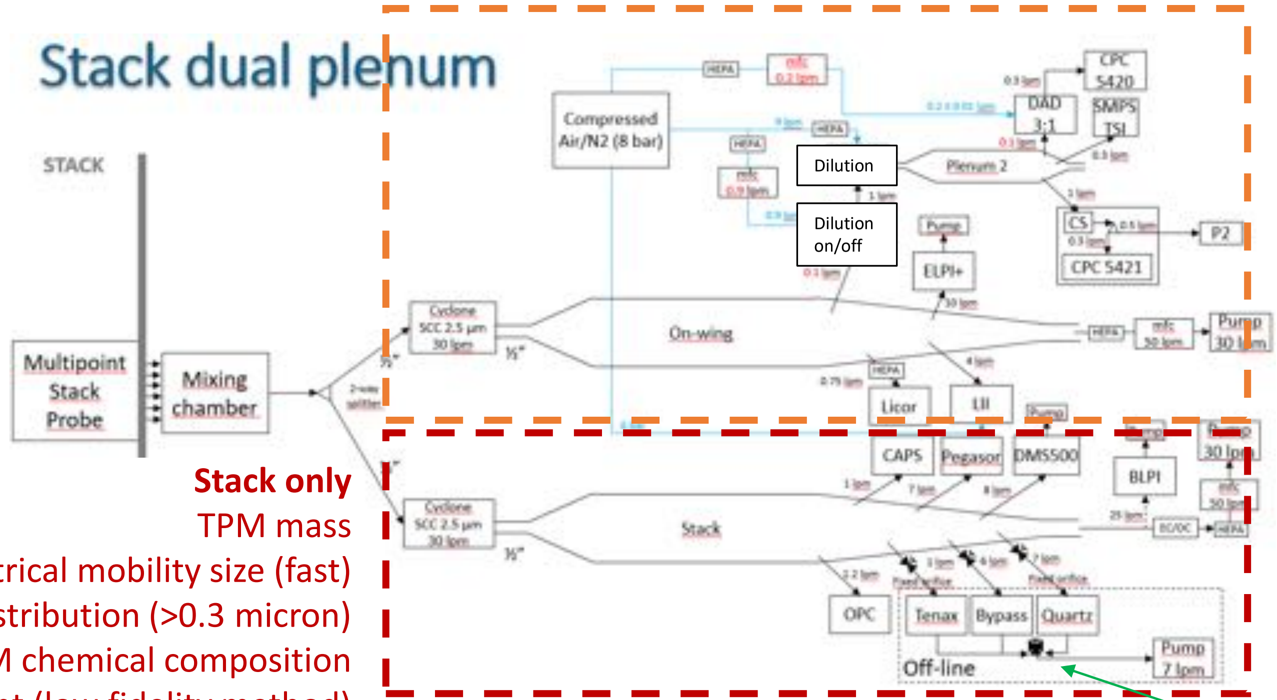



Health

# Baseline measurement system

nvPM number count (high & low fidelity)
TPM number count
TPM electrical mobility size (slow)
TPM aerodynamic particle size
nvPM mass
$CO_2$
(calculation of Emission Indices)

**Baseline system common across stack/onwing/airport ambient**




**Stack only**
TPM mass
TPM electrical mobility size (fast)
TPM particle scattering size distribution (>0.3 micron)
TPM chemical composition
TPM particle count (low fidelity method)
nvPM particle absorption

**Sampling offtakes available for filters**

AVIATOR TUBE RAPTOR

Health Impact of UFP – workshop 15th Sept 2020

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# Task 2.2 Calibration and inter-comparison

INTA, RR, UoM, CU, ONERA, CIEMAT, IA (M3–M24)

- Traceable measurements are key in establishing definite conclusions and inter-comparisons of the measurement WP's.
- Analysers will be traceably calibrated according to the manufacturer or regulatory recommendations prior to measurement campaigns
- Intercomparisons between low and high fidelity particle number/size kit

Prior to the specific tests, intercomparisons of 'like-for-like' instruments will be performed by the consortium using numerous surrogate aerosols (e.g. salt, miniCAST soot, Palas graphite, PSL spheres etc.) this will enable quantification and correction of differences between instruments whilst minimising the risk of data being affected by shipping damage



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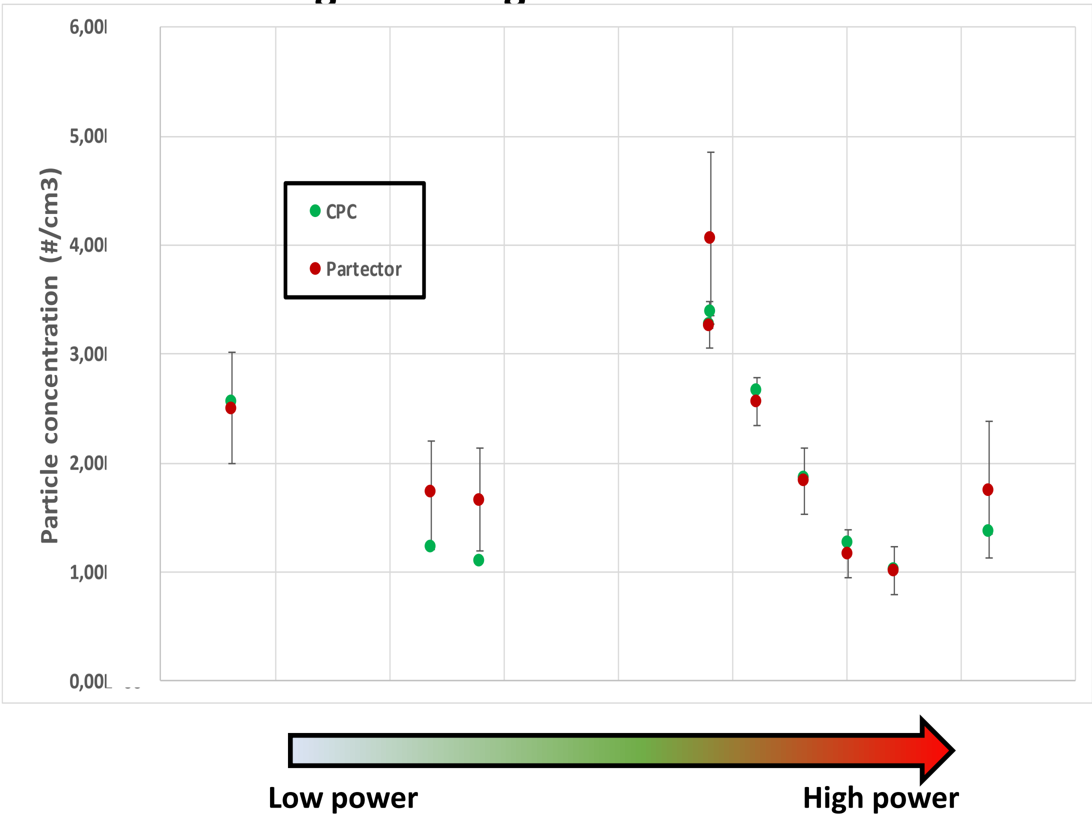
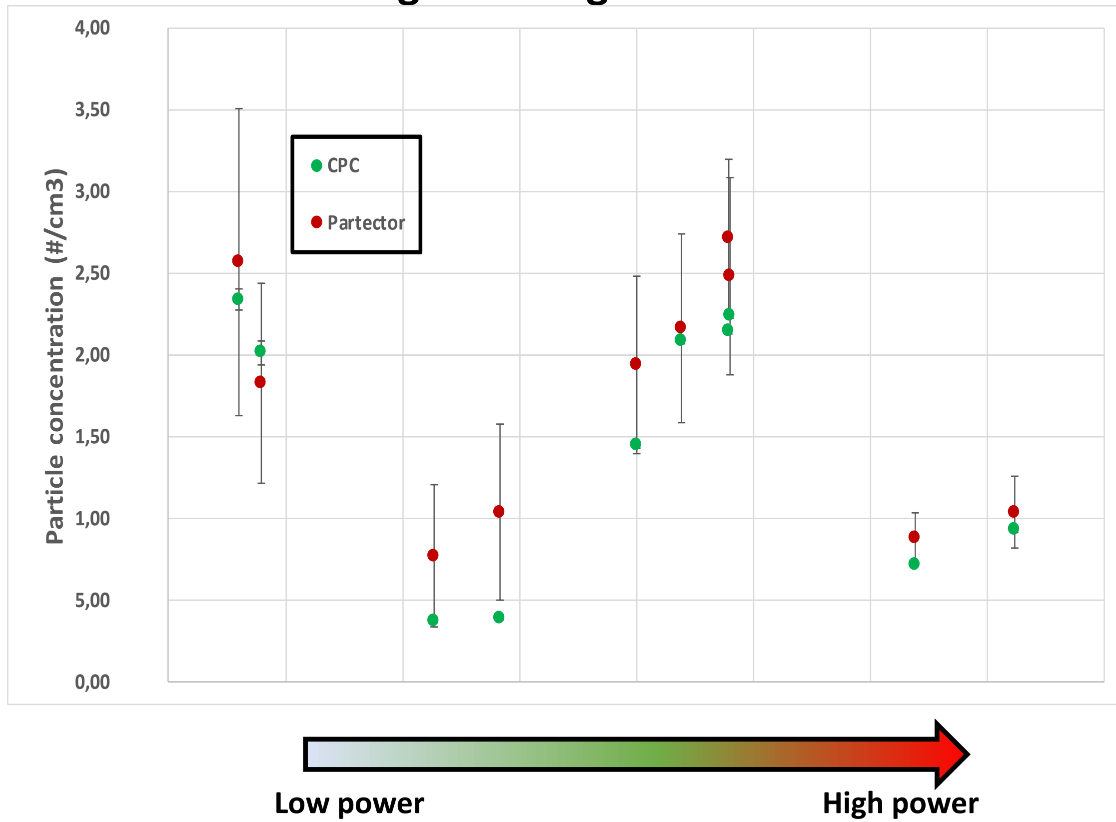
# Stack data example – Intercomparison CPC (high fidelity) vs Partector 2 (low fidelity)

Engine configuration 2




Engine configuration 3




Partector2 has the same trend as High Fidelity Sensor (CPC)

Partector2 slightly higher than CPC

Health Impact of UFP – workshop 15th Sept 2020

…ject has received funding from the European Union's …2020 research and innovation programme under grant agreement No 814801

# Task 2.3 **Piggyback Engine testing**

- These measurements will be acquired using the developed baseline measurement system and will both guide the development of the dedicated measurements suite and enable modelling WP’s to commence.
- Piggyback existing engine tests at INTA (Trent engine development testing)
  - Engine variability
  - Range of engine conditions (low to high power)
  - Potentially range of ambient conditions
  - Repeatability



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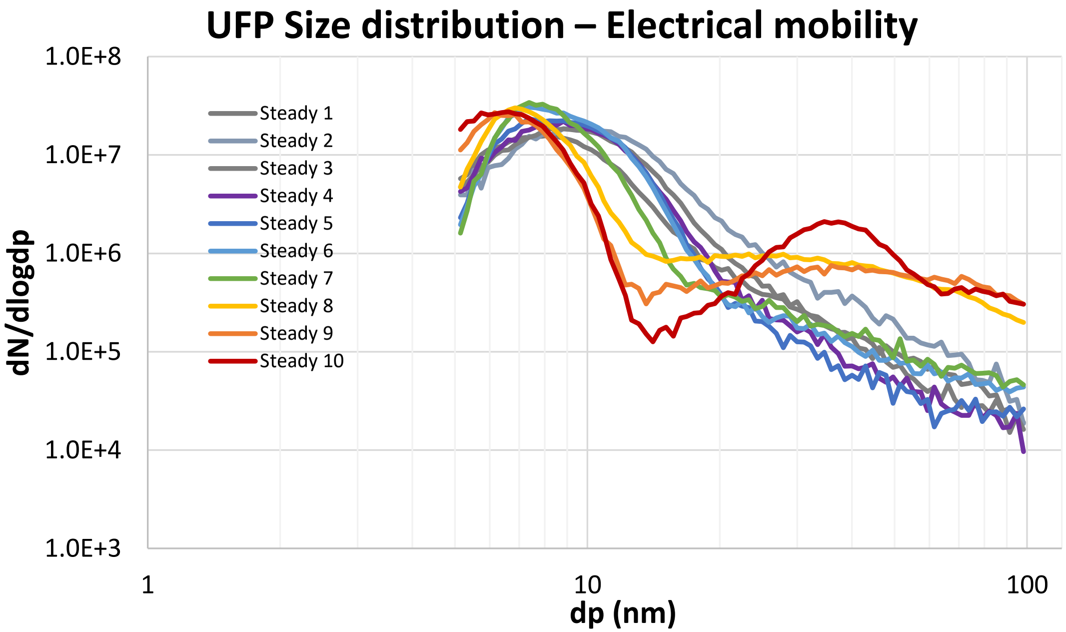
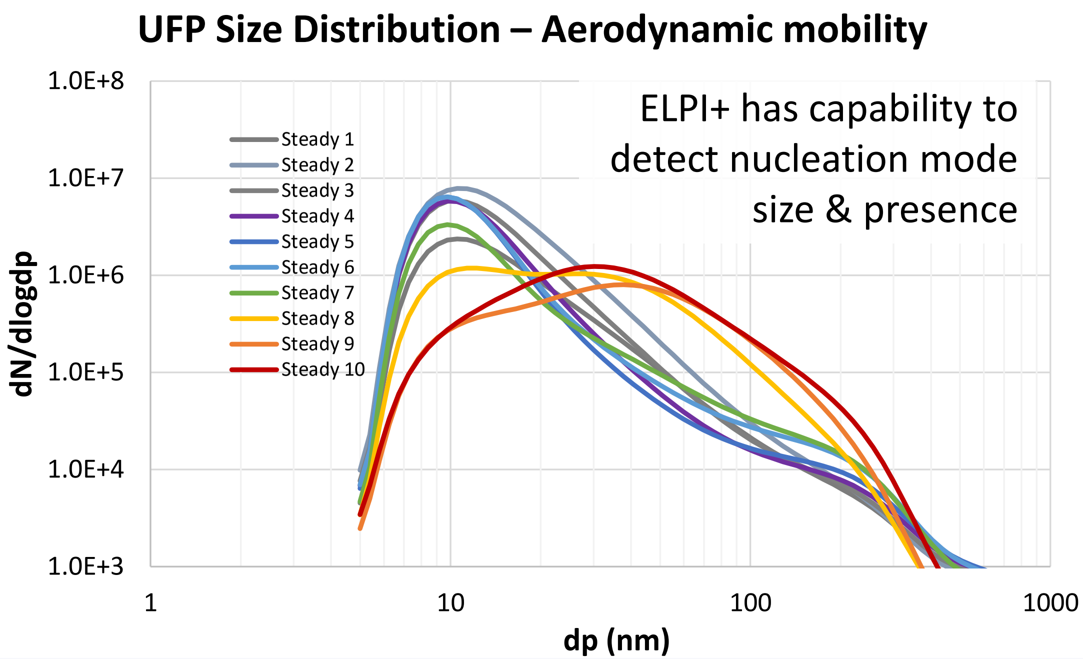
# Stack Data – Electrical vs Aerodynamic PSD

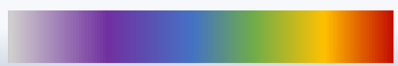
- Evaluation of particle size measurement methods

nanoDMA (electrical) common in aerosol science

ELPI+ (Aerodynamic) preferred by the modellers



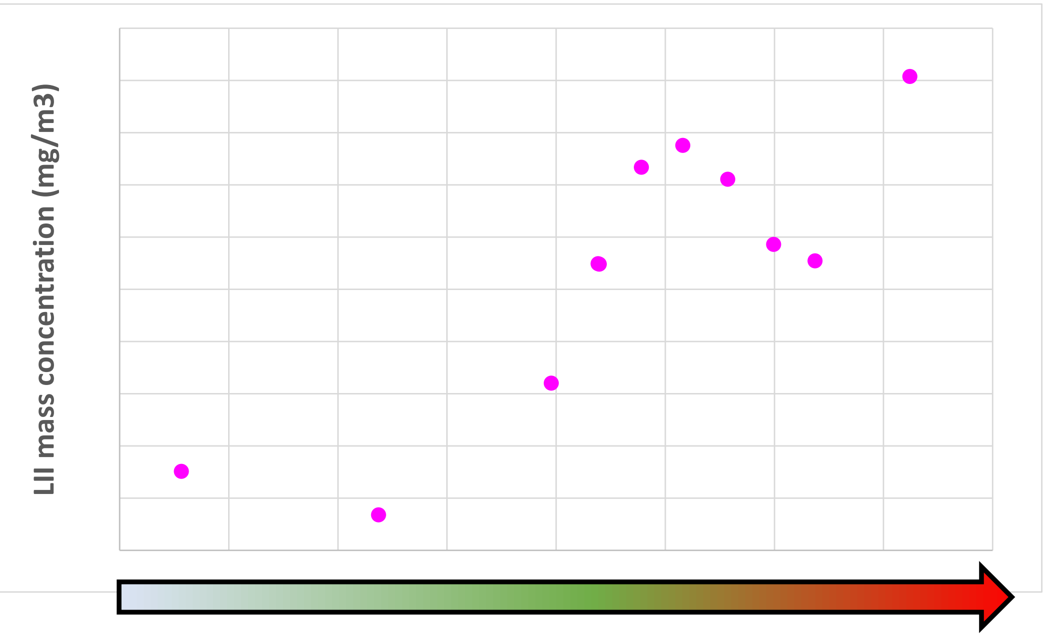



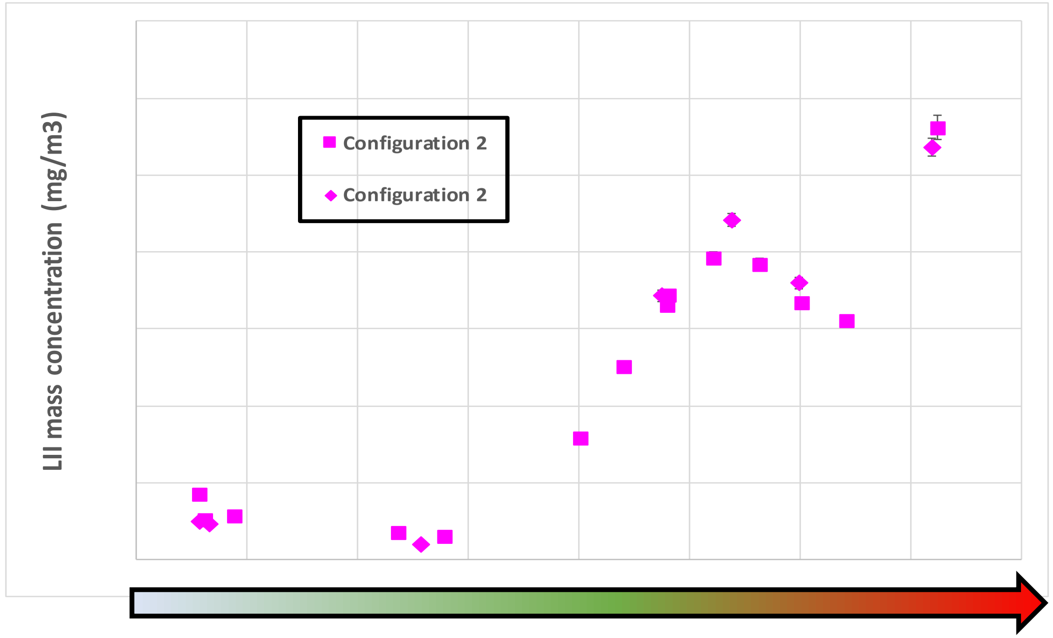

Funded by the Horizon 2020 Framework Programme of the European Union

# Engine exit vs stack example: nvPM mass

## ENGINE EXIT PLANE




## STACK




**Low power (idle)** **High power (Take-off)**

DIFFERENT DAY, DIFFERENT ENGINE CONFIGURATION → GOOD CORRELATION

ESTIMATED DILUTION FACTOR OF ~15 to 20

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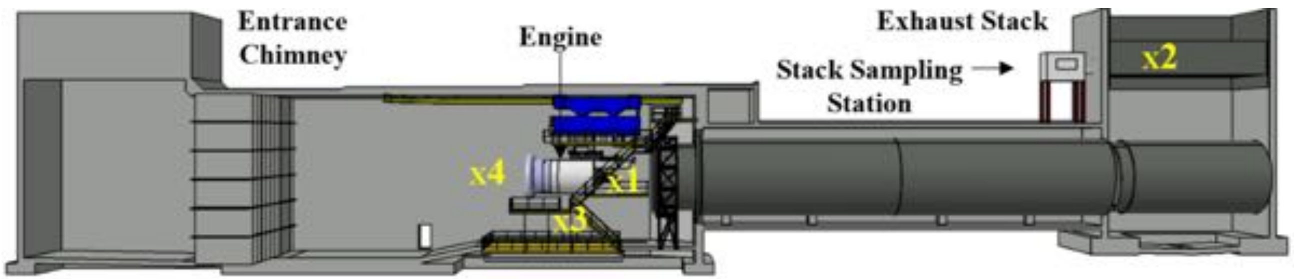
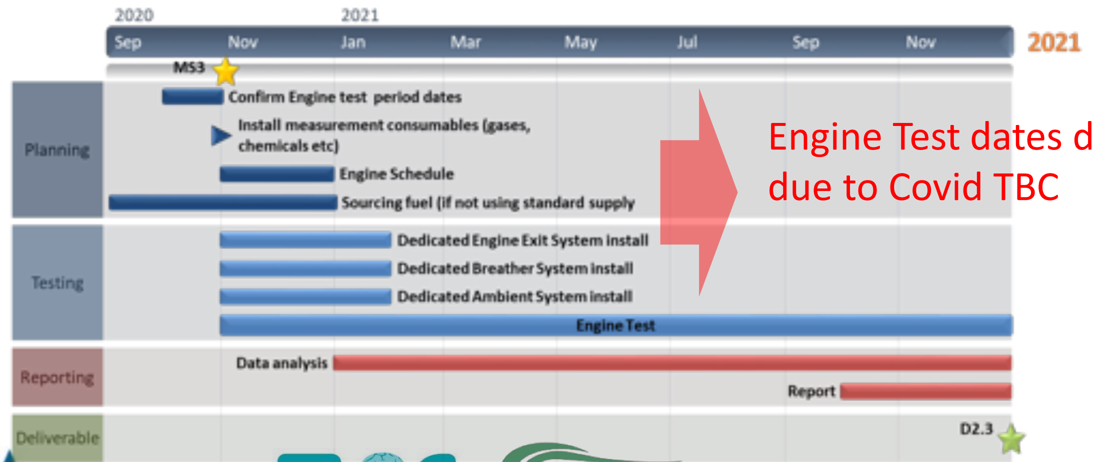
# Task 2.4 Dedicated testing

- The dedicated and baseline measurement suites will be used to fully characterise a RR Trent aircraft engine emitted gaseous and PM concentrations across a full power curve.
  - Likely XWB (but not guaranteed due to engine testbed schedules)
- Plan to piggyback engine(s) prior to dedicated test to shakedown the comprehensive system (do not need full set of analysers to do this)




Engine Test dates delayed due to Covid TBC

Minimum dedicated engine test curves:
Multiple test points from Ground Idle (below 7% LTO) all the way up to Take-Off condition

- Repeated with and without oil breather mixing with plume
- If possible a repeat at different ambient conditions



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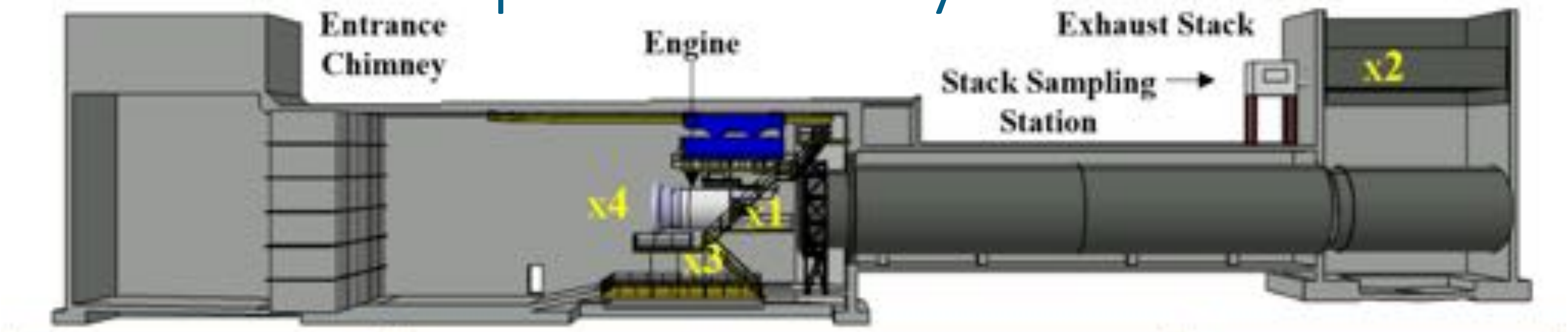
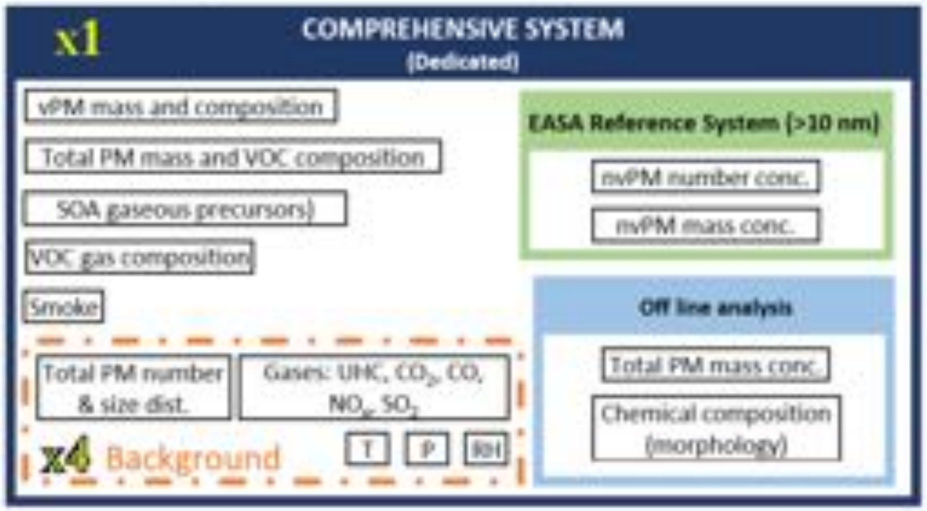
# Test-cell engine emission measurement schematic – comprehensive system




System will also be used for on-wing and ambient testing




Lots of kit from multiple partners



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NRC·CNRC

NRC.CANADA.CA

# Aircraft Engine PM Emissions – On-wing and Downstream Measurements

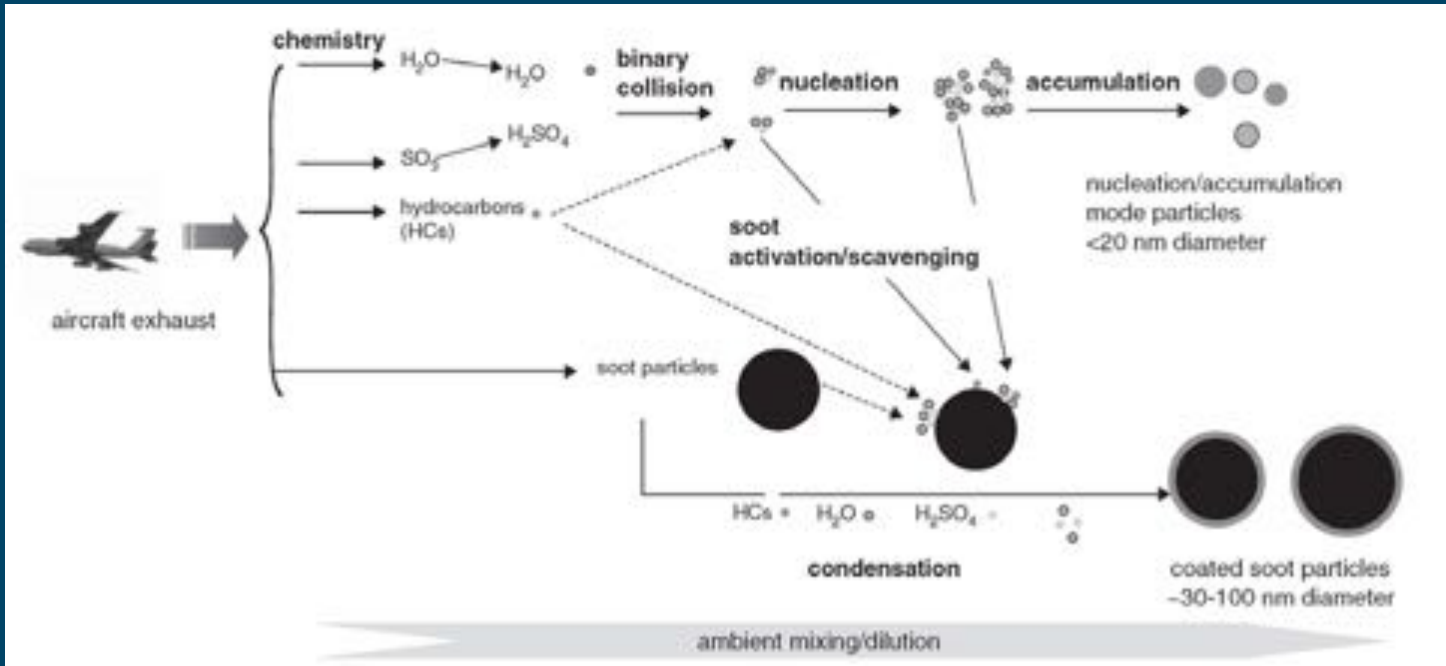
Prem Lobo

Health Impact of UFP Workshop
15 September 2020

National Research Council Canada | Conseil national de recherches Canada

Canada

# Aircraft Engine PM emissions




*Whitefield, P.D. et al., 2008, ACRP Report 9, Transportation Research Board, Washington, D.C.*

**Aircraft Engine PM emissions are typically presented as the *number or mass of PM per kg of fuel burned***

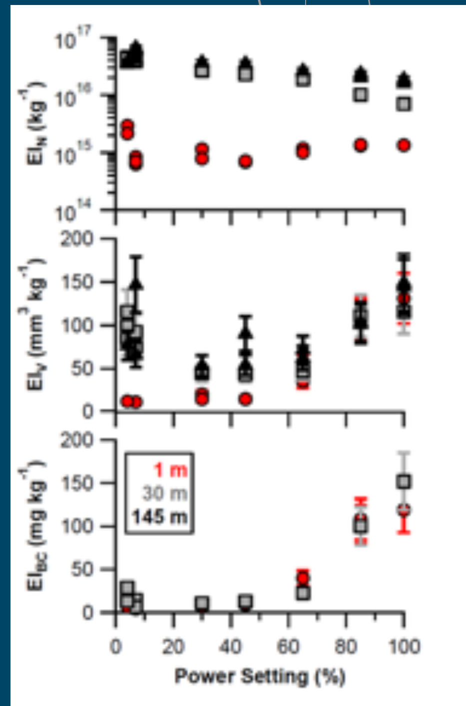
EIn: number-based emission index (#/kg fuel burned)

EIm: mass-based emission index (mg/kg fuel burned)

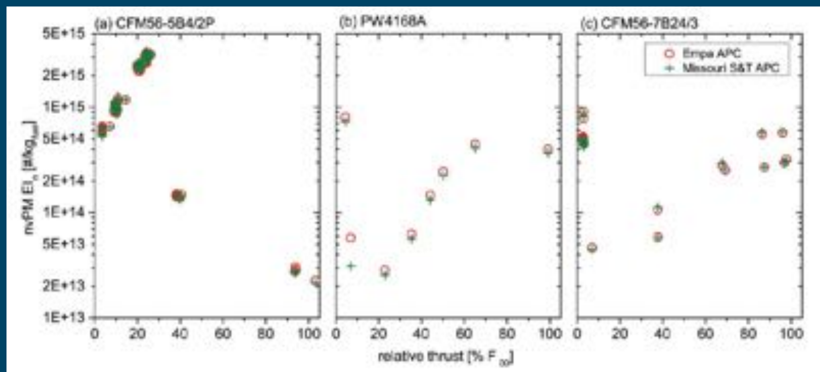
# Aircraft Engine PM emissions

- **Aircraft engine PM emissions vary as a function of**
  - Engine type
  - Engine operating condition
  - Fuel composition
  - Sampling location
- **Parameters used to characterize aircraft engine PM emissions**
  - Number
  - Mass
  - Composition
  - Size

CFM56-2C1




*Beyersdorf et al., 2014, Atmos. Chem. Phys., 14, 11–23*

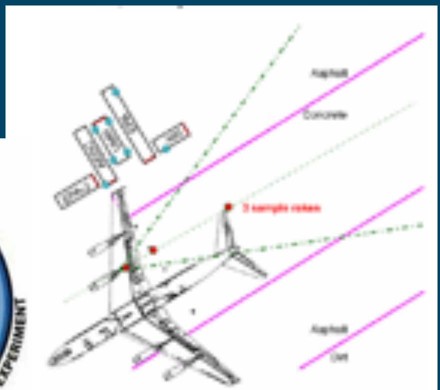


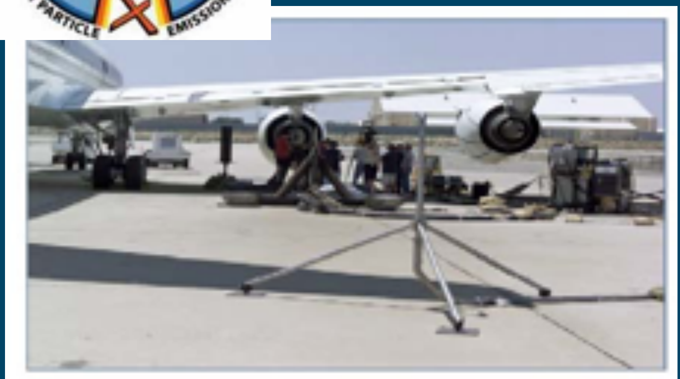

*Lobo et al., 2015, Aerosol Sci. Technol. 49, 472-484*

# Aircraft Engine PM emissions - measurement

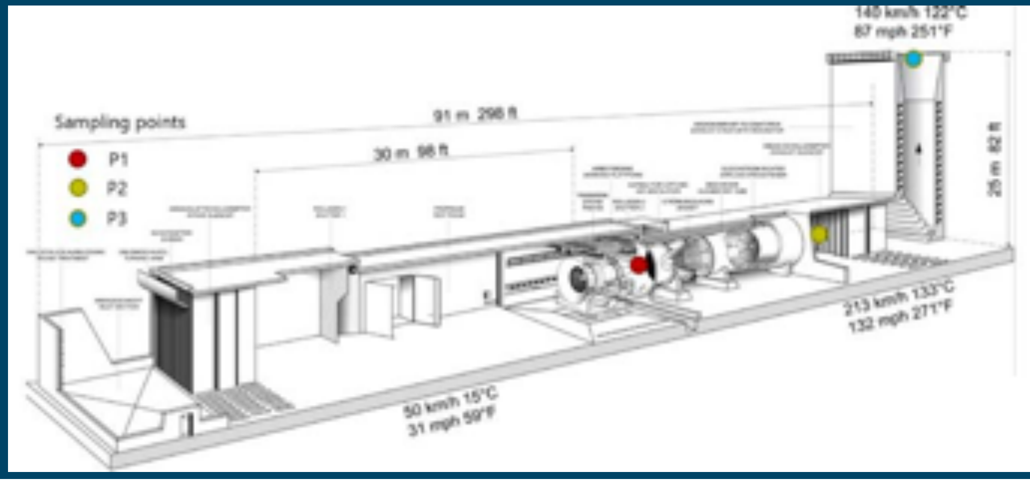
- **Number**
  - Condensation Particle Counter (CPC)
- **Mass**
  - Photoacoustic Spectroscopy, Laser Induced Incandescence
- **Composition**
  - Aerodyne Mass Spectrometer (Organics, sulfates, non-refractory BC)
  - Thermal Optical Analysis (elemental carbon, organic carbon)
- **Size**
  - Mobility Diameter
    - Scanning Mobility Particle Sizer (SMPS)
    - DMS 500, EEPS
  - Aerodynamic diameter
    - ELPI

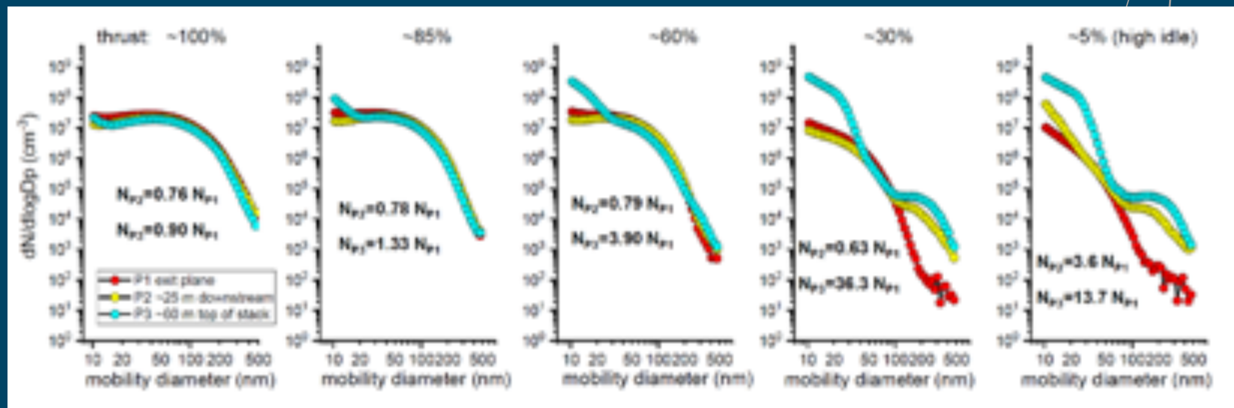
# On-wing and downstream PM emissions measurements





Wey et al., 2006, NASA/TM-2006-214382, ARL-TR-3903



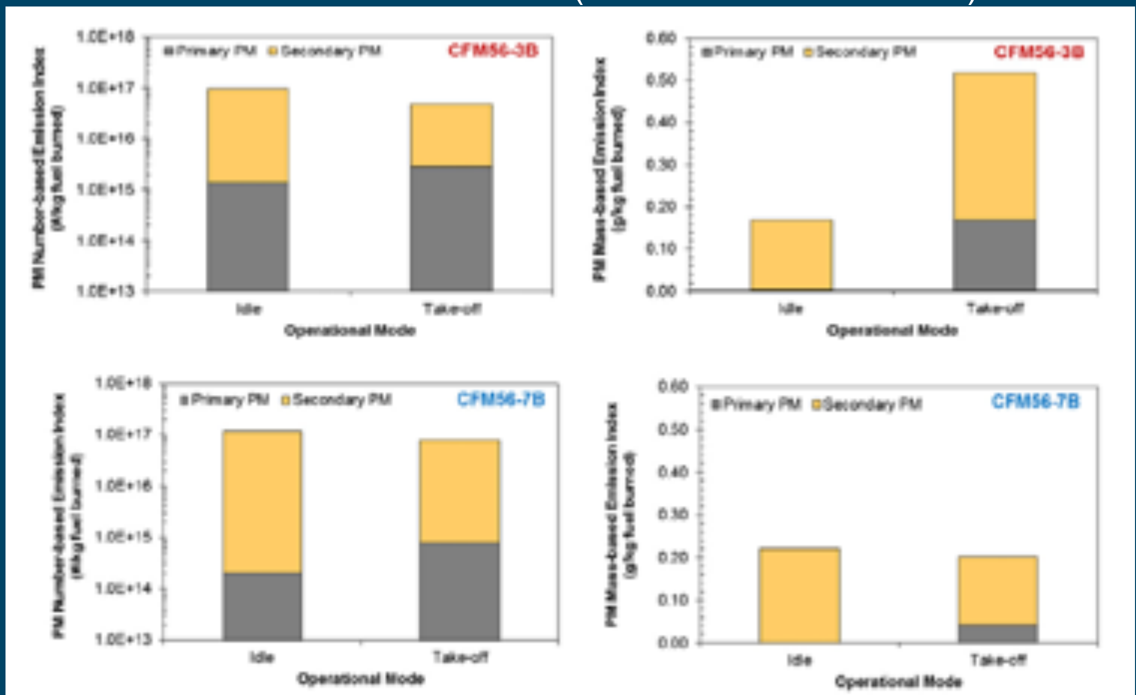




Durdina et al., 2020, in prep

# Plume evolution

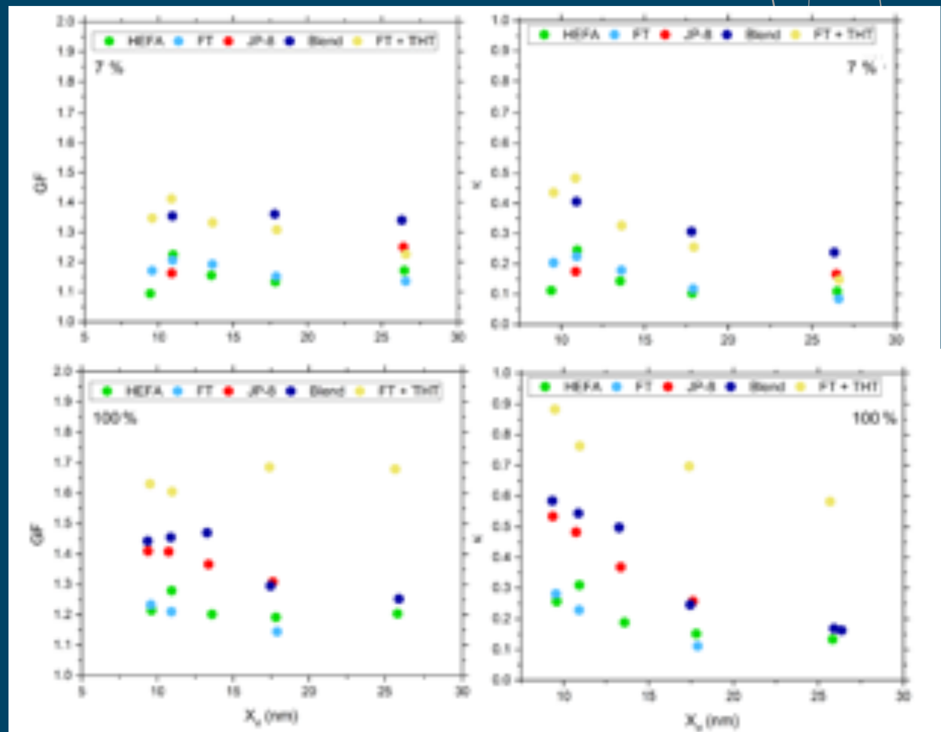
➢ **Condensation of volatile species occurs as the exhaust plume expands and cools**

CFM56-3B/CFM56-7B (100-300m downstream)



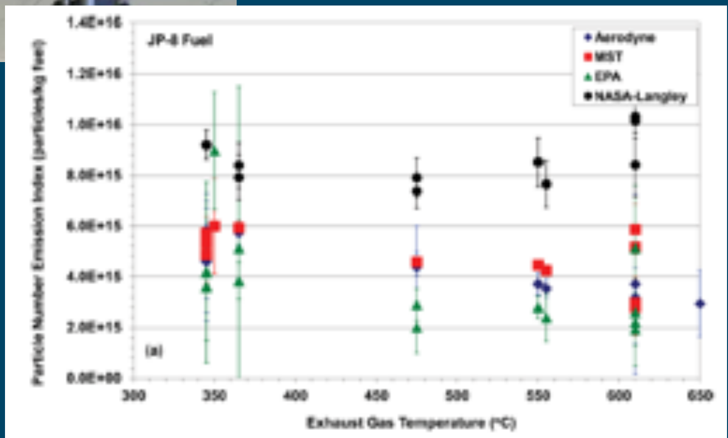

*Lobo et al., 2012, Atmos. Environ., 61, 114-123*

CFM56-2C1 (143m downstream)

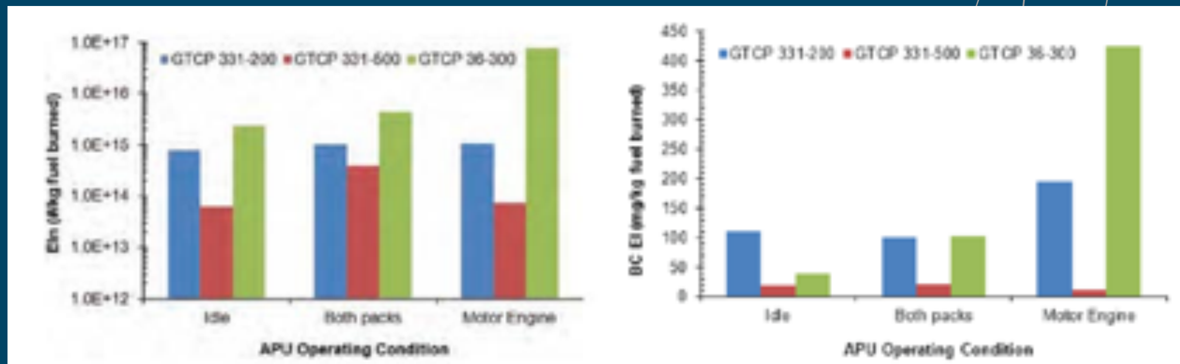



*Trueblood et al., 2018, Atmos. Chem. Phys., 18, 17029-17045*

# APU PM Emissions Measurements




Kinsey et al., 2012, J. Air Waste Manage. Assoc., 62, 420-430




Lobo et al., 2013, ACRP Report 97, Transportation Research Board

# AVIATOR – On-wing Engine and APU emissions measurements

**WP3:** On-wing engine exit and downstream plume and APU measurements

## Participants:

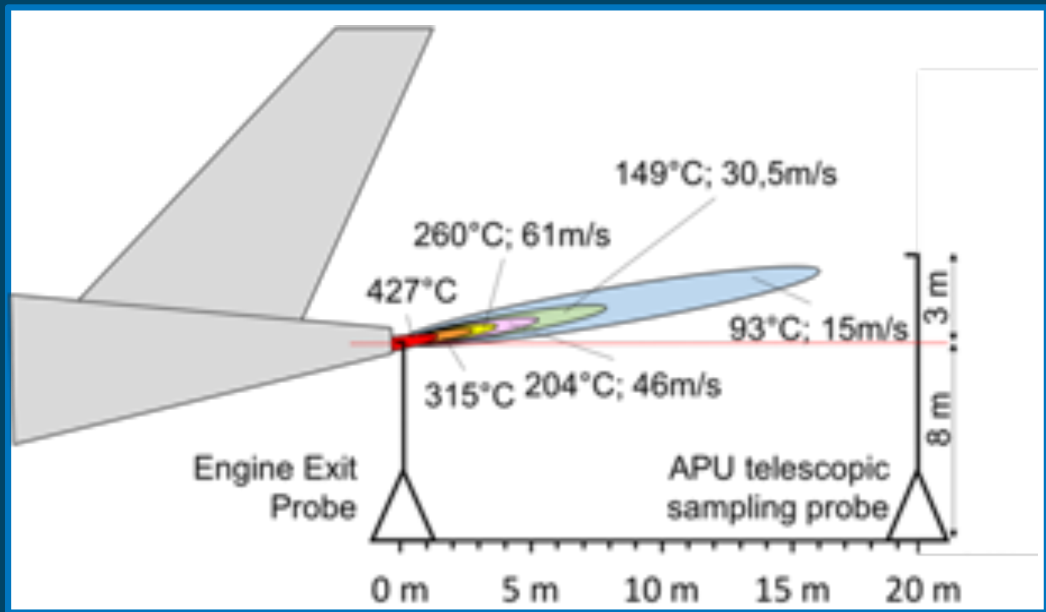
Cardiff University / Prifysgol Caerdydd
GTRC Gas Turbine Research Centre
IBERIA
Gobierno de España / Ministerio de Defensa
INTA Instituto Nacional de Técnica Aeroespacial
Rolls Royce
Manchester Metropolitan University
Manchester 1824
Gobierno de España / Ministerio de Ciencia, Innovación y Universidades / Ciemat
ONERA The French Aerospace Lab
IngenieríaAnalítica Chromatography & Spectrometry
National Research Council Canada / Conseil national de recherches Canada

## Objectives:

- To measure on-wing main engine emissions.
- To measure emissions from aircraft engines using drop-in alternative fuel.
- To measure APU emissions.

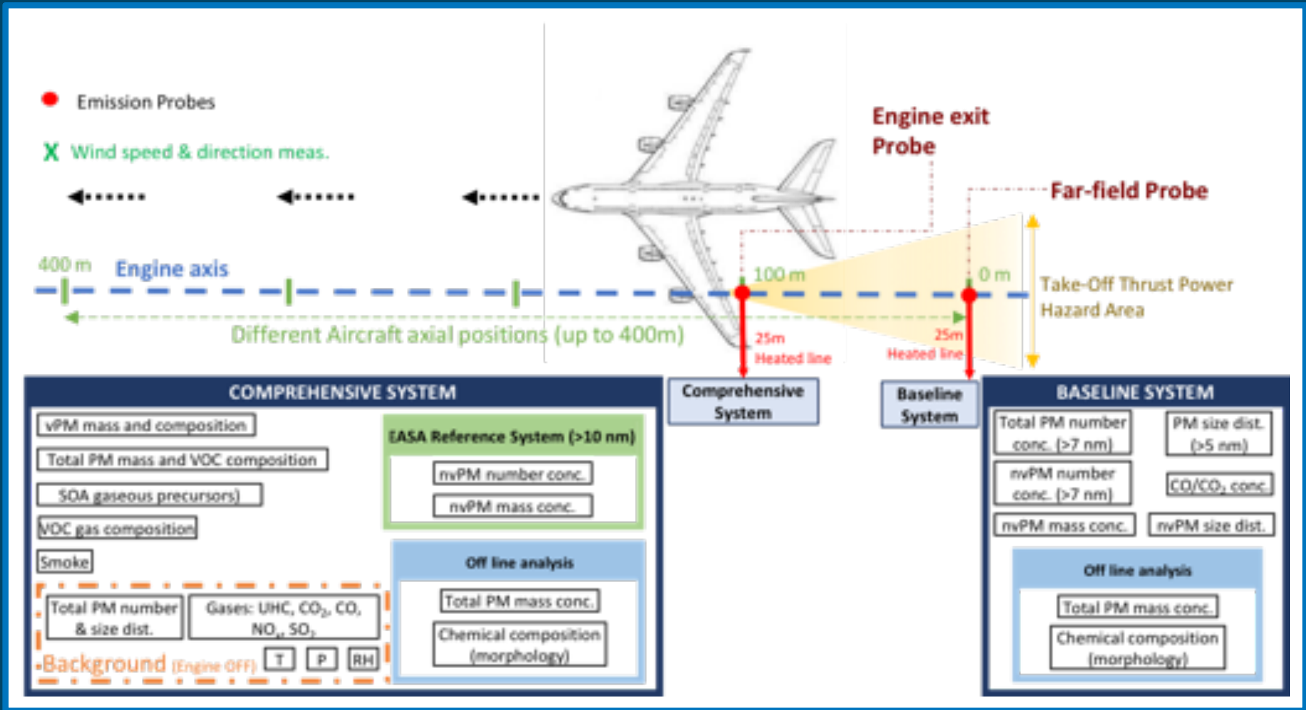
# AVIATOR – On-wing Engine and APU emissions measurements

**To develop and install a suite of sampling probes** for measurement of APU exhaust and main engine plume evolution during on-wing engine tests.



# AVIATOR – On-wing Engine and APU emissions measurements

High-fidelity emissions measurements (gaseous and PM) on-wing at engine exit and in the evolving plume of main engine and APU to determine the impact seasonal variation and fuel composition.



NRC·CNRC

NRC.CANADA.CA

# Thank you

Dr. Prem Lobo

Team Leader, Black Carbon Metrology

Prem.Lobo@nrc-cnrc.gc.ca

National Research Council Canada | Conseil national de recherches Canada

Canada

# AVIATOR

## Assessing aViaton emission Impact on local Air quality at airports: TOwards Regulation

*LC-MG-1-1-2018 InCo flagship on reduction of transport impact on air quality*

# AVIATOR

Open questions:

- How does the aircraft plume chemically evolve while sampling point is moving away from the runway?
- How the climatic conditions influence the aircraft plume?
- What is the SOA formation potential for varying alternative fuels?

# **WP4:** Ambient measurements and sensor network development.

To perform high-fidelity measurements of air quality at Madrid-Barajas airport over a range of climatic conditions

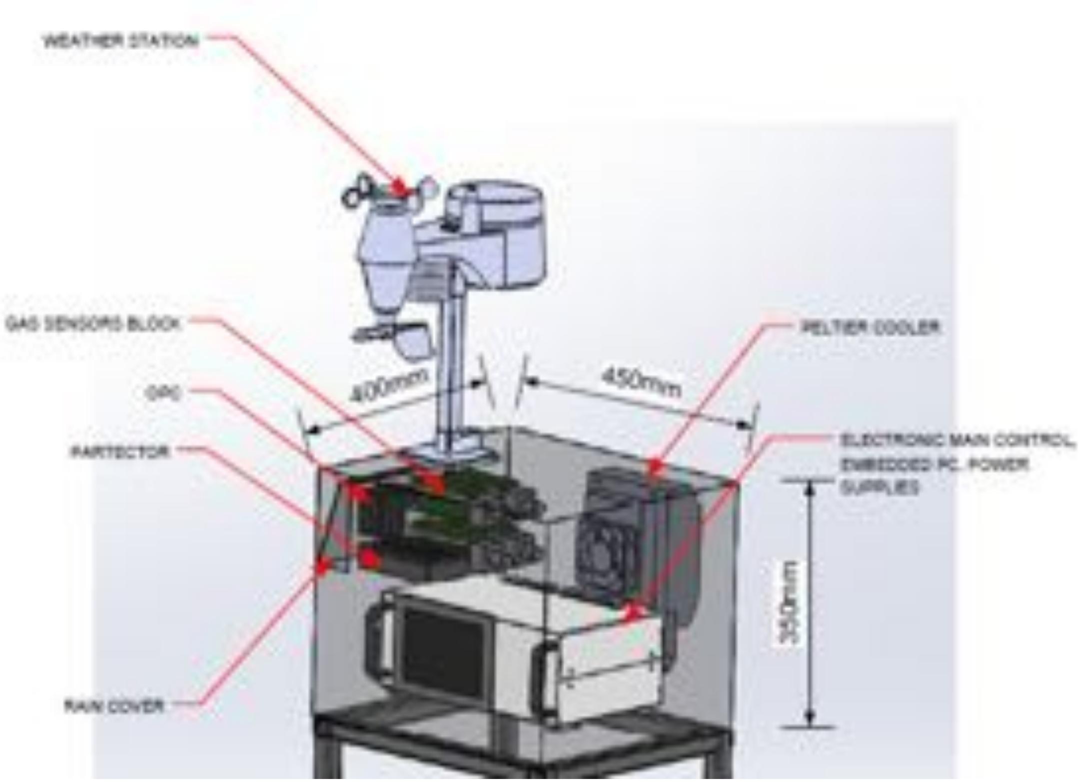
To develop a proof of concept low-cost and low-intervention sensor network.

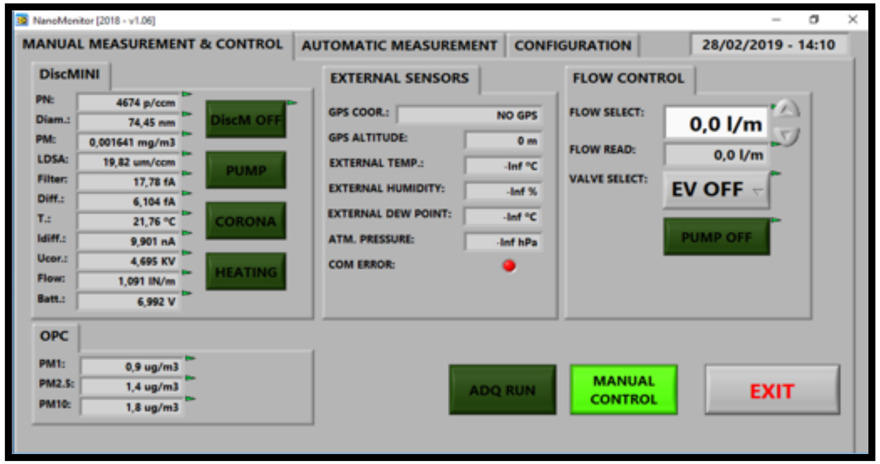
To deploy the LCS at three climatically different airports (Madrid-Barajas, Copenhagen and Zurich), to provide routine data on temporal and spatial variability of key pollutants including UFP, total PM, CO, $CO_2$, NO, $NO_2$, $SO_2$, $O_3$ and VOC

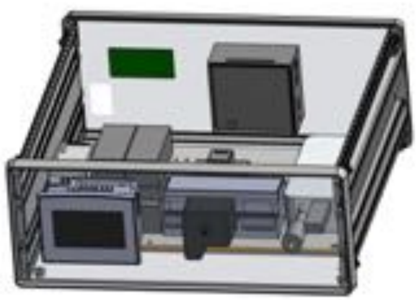
# Low-cost sensor network


- 15 – 20 nodes around Madrid airport
- ~14 months deployment
- Co-locate with existing stations
- Additional validation with mobile measurements
- Reduced network at CPH and ZRH

# RAMEM Low cost sensor proposal





Instrument with three main parts

**Meteorological monitoring**

- Temperature
- Pressure
- RH
- **Wind v and dir.**

**Gas detection.**

**CO, $CO_2$, $SO_2$, $O_x$, NO, $NO_2$ and VOCs:**

Specific sensors with modular concept: the array of sensors can be selected (Alphasense & Sensair)

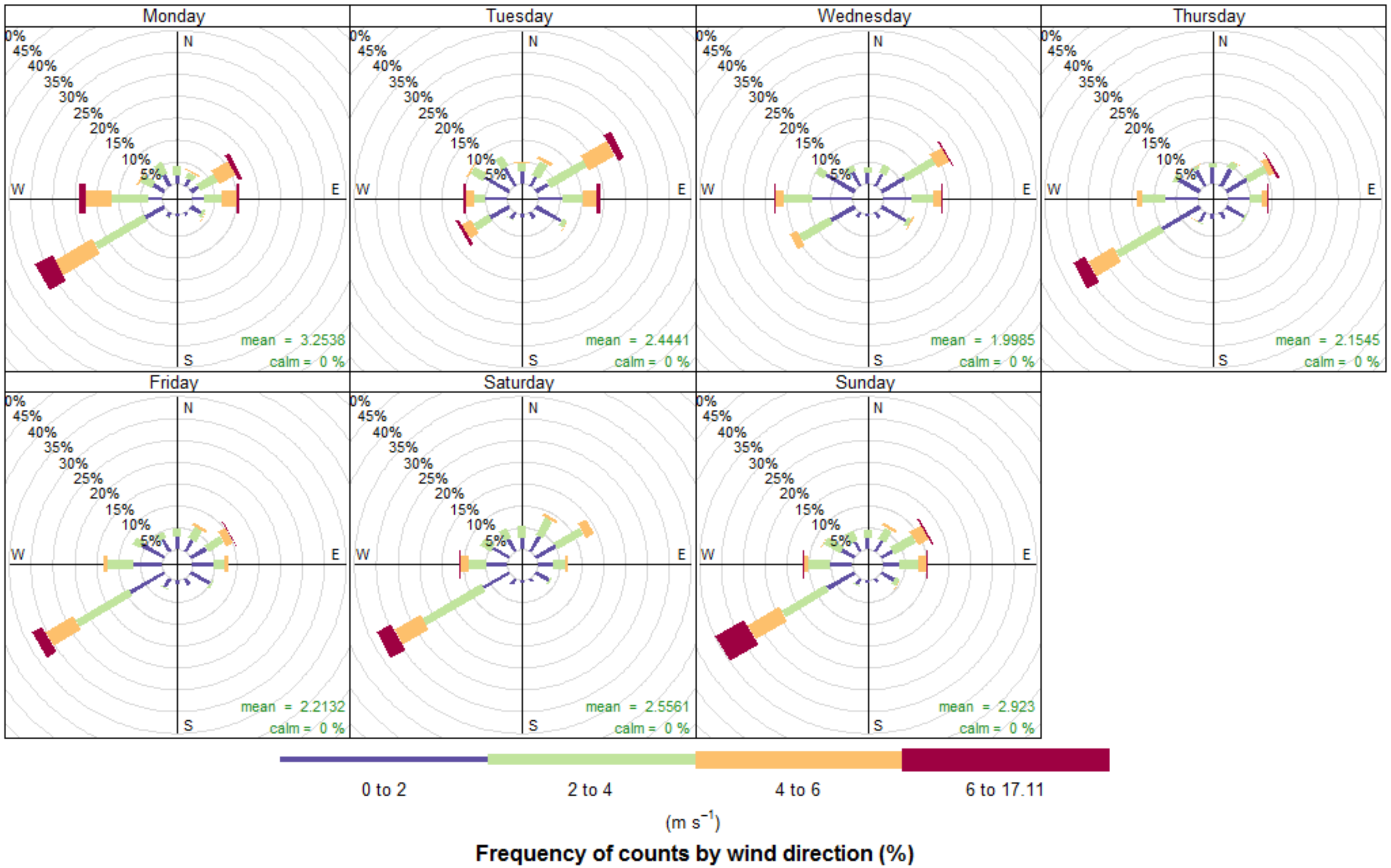
**4 sensor per species (except CO2 & VOCs)**

**Particle detection**

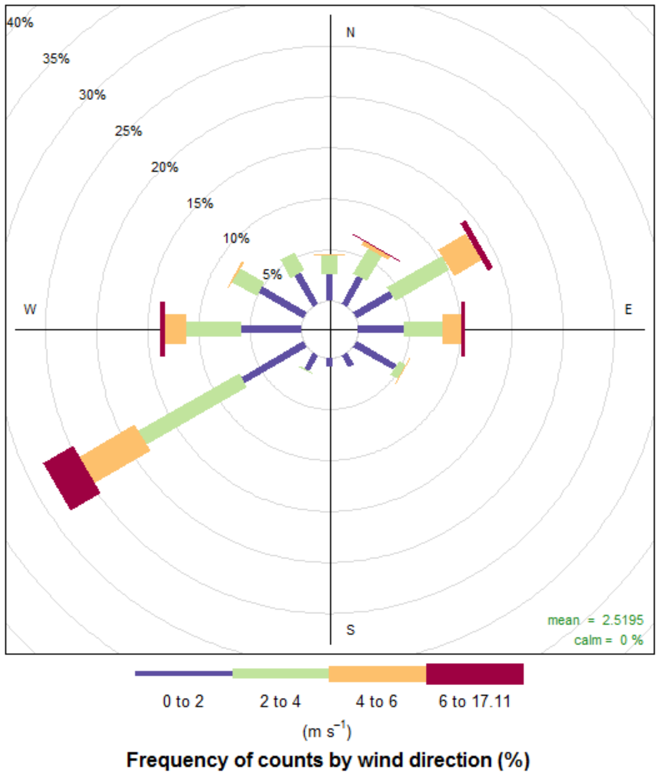
**PM1, 2.5, 10 (OPC) and UFP from 10 to 700nm (Diffusion Charger - Naneos)**

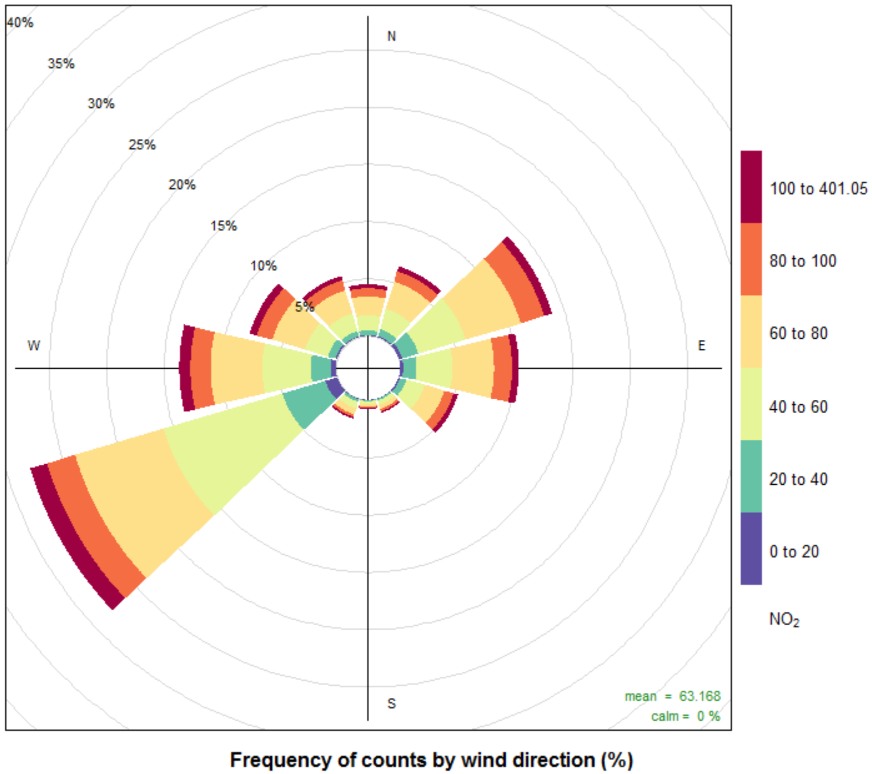
Different inlets for both instruments

# Source apportionment using WS & WD

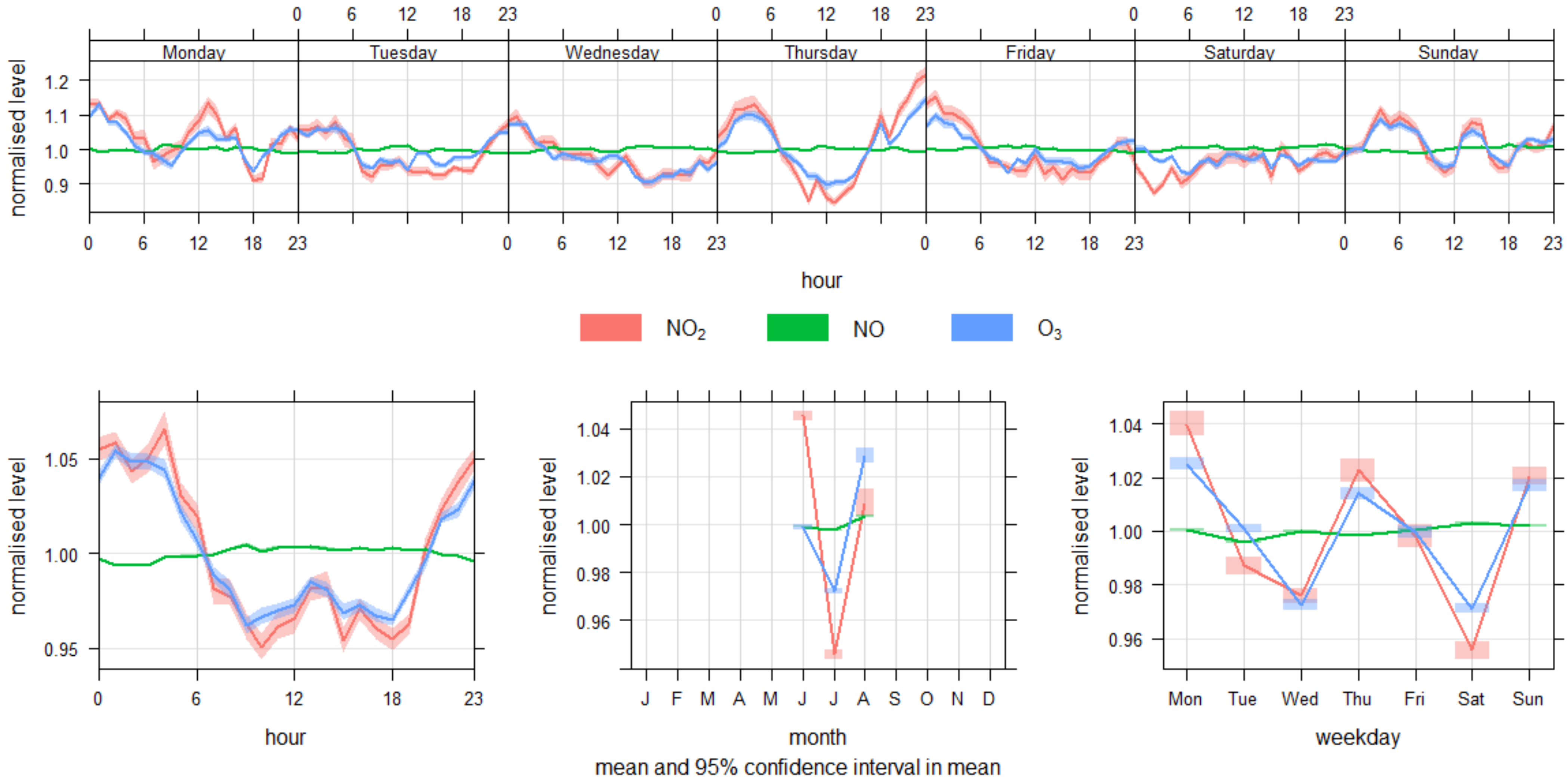


# Windroses to Pollutionroses



# Time Series Patterns



# Making use of a Potential Aerosol Mass (PAM) Reactor as part of the setup

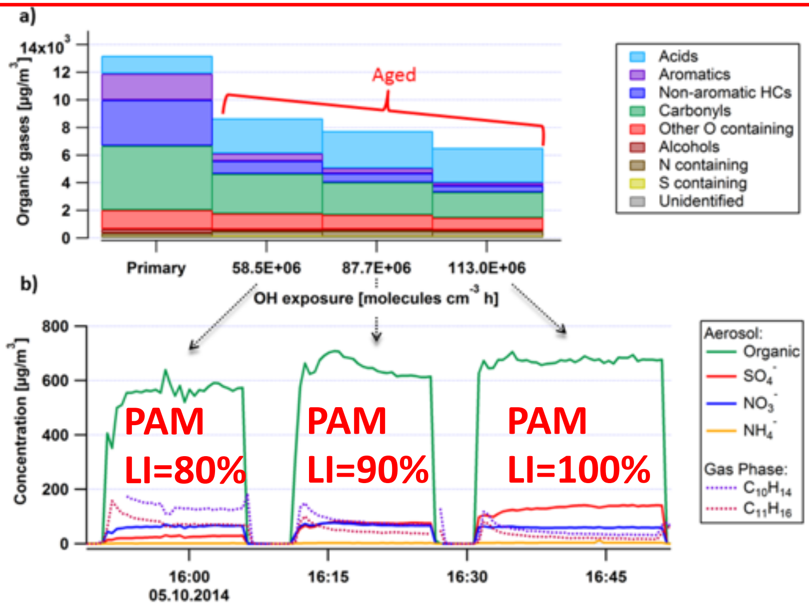
SOA Precursors
(VOCs)
$N_2$, $H_2O$, $O_2$
$O_3$

**$O_3 + H_2O + UV \rightarrow 2OH + O_2$**
**$VOC, SO_2 + OH \rightarrow$ Secondary Aerosol**

Secondary Aerosol
VOCs (mostly
oxidized)

**Organic Gases (VOCs)**

**Secondary Aerosol**




**We will have a new PAM with an external integrated $O_3$ chamber and humidifier.**

Zurich University
of Applied Sciences

## Centre for Aviation
## ZHAW School of Engineering

# Acute response of human bronchial epithelial cells (BEAS-2B) after exposure to aircraft turbofan engine non-volatile PM

Lukas Durdina
15 September 2020
Health impacts of UFP – workshop

# Paper published in Communications Biology

COMMUNICATIONS BIOLOGY

ARTICLE

https://doi.org/10.1038/s42003-019-0332-7 OPEN

## Non-volatile particle emissions from aircraft turbine engines at ground-idle induce oxidative stress in bronchial cells

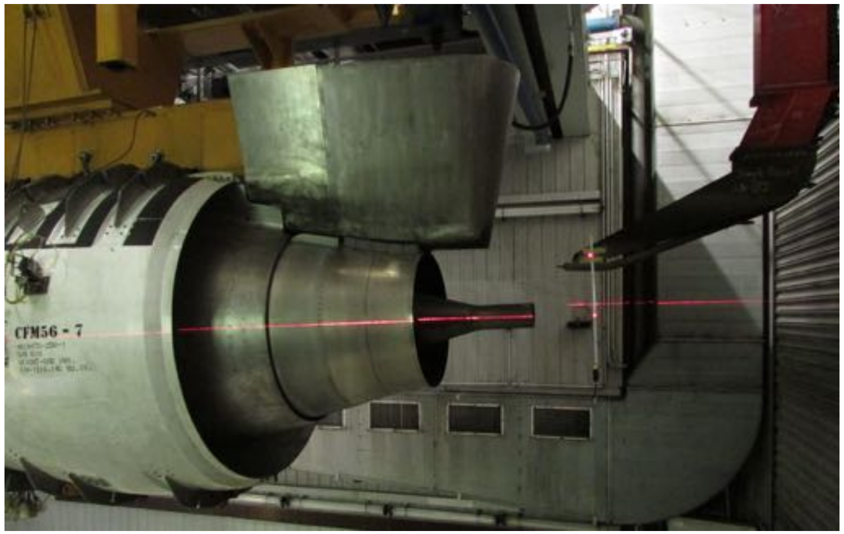
Hulda R. Jonsdottir[1], Mathilde Delaval[1], Zaira Leni[1], Alejandro Keller[2], Benjamin T. Brem[3,6], Frithjof Siegerist[4], David Schönenberger[3], Lukas Durdina[3,7], Miriam Elser[3,8], Heinz Burtscher[2], Anthi Liati[5] & Marianne Geiser[1]

- Credit for all the cells work goes to Dr. Hulda Jonsdottir and her colleagues from University of Berne (now at Spiez Laboratory)
- Funding by two projects from the Swiss Federal Office of Civil Aviation (FOCA): 2015-113 (EMPAIREX) and 2016-037 (REHEATE)

# Objectives

- Measure acute toxicity (cytotoxicity and oxidative stress) of BEAS-2 cells after one hour exposure to nvPM from a turbofan engine
  - Effect of engine thrust: high thrust (~85%) vs low thrust (idle)
  - Effect of fuel composition

# Engine and test cell

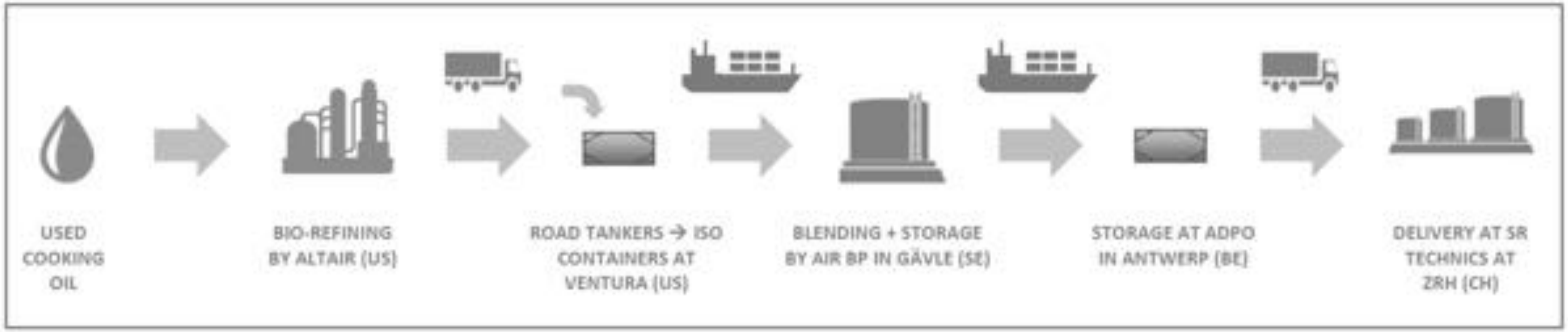



- CFM56-7B (Boeing 737NG) in the test cell at SR Technics, Zurich airport
  - The engine was leased for 2 weeks
  - 7 test points from idle to take-off

- 2D traversable single-orifice exhaust probe (< 1 m from the engine exhaust nozzle)

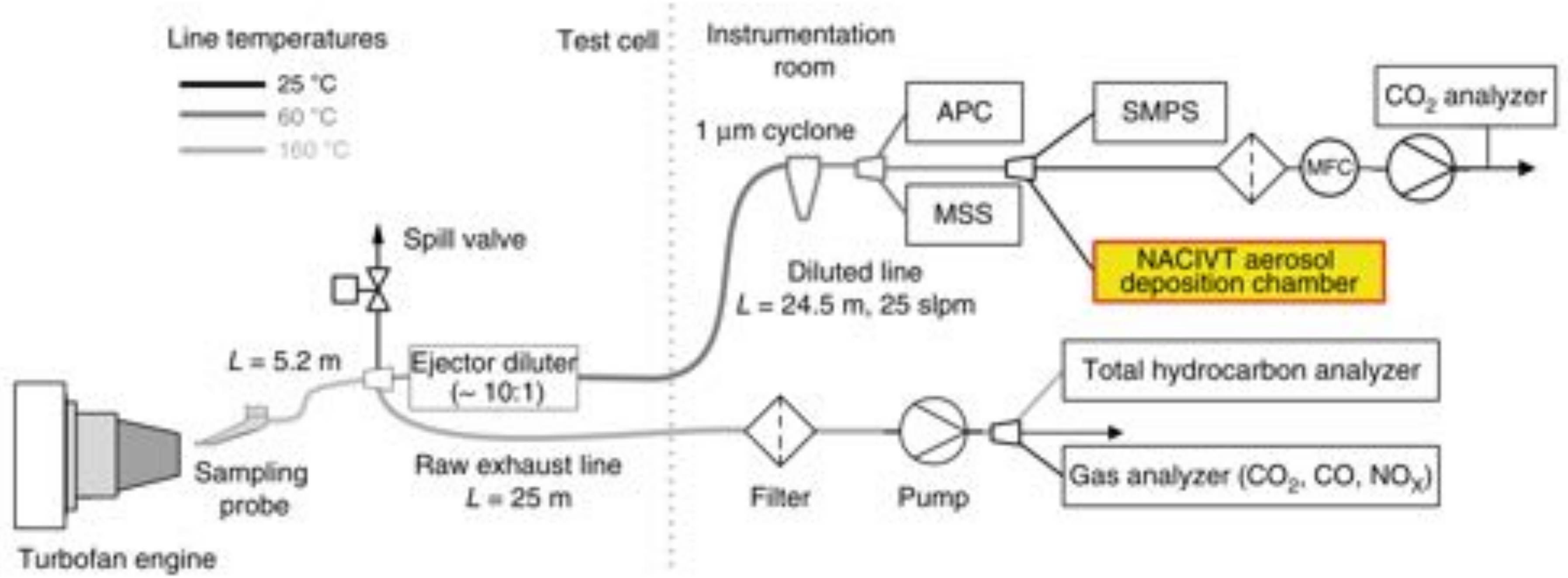
Zurich University of Applied Sciences

# The engine was fueled with regular Jet A-1 (18.1% arom. and 13.6% H) and with a 32% HEFA blend (11.3% arom. and 14.1% H)



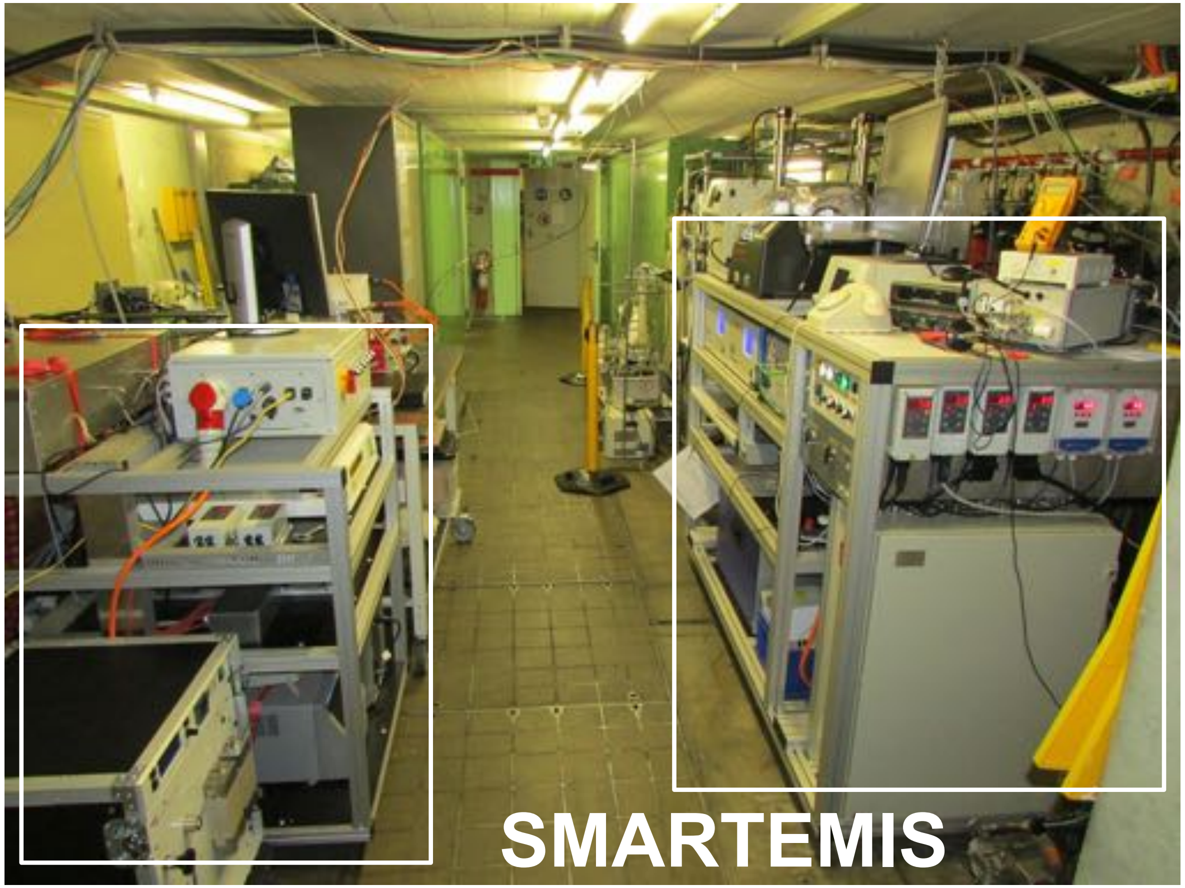

- HEFA from used cooking oil (UCO)
- 32.000 liters (two ISO containers) used

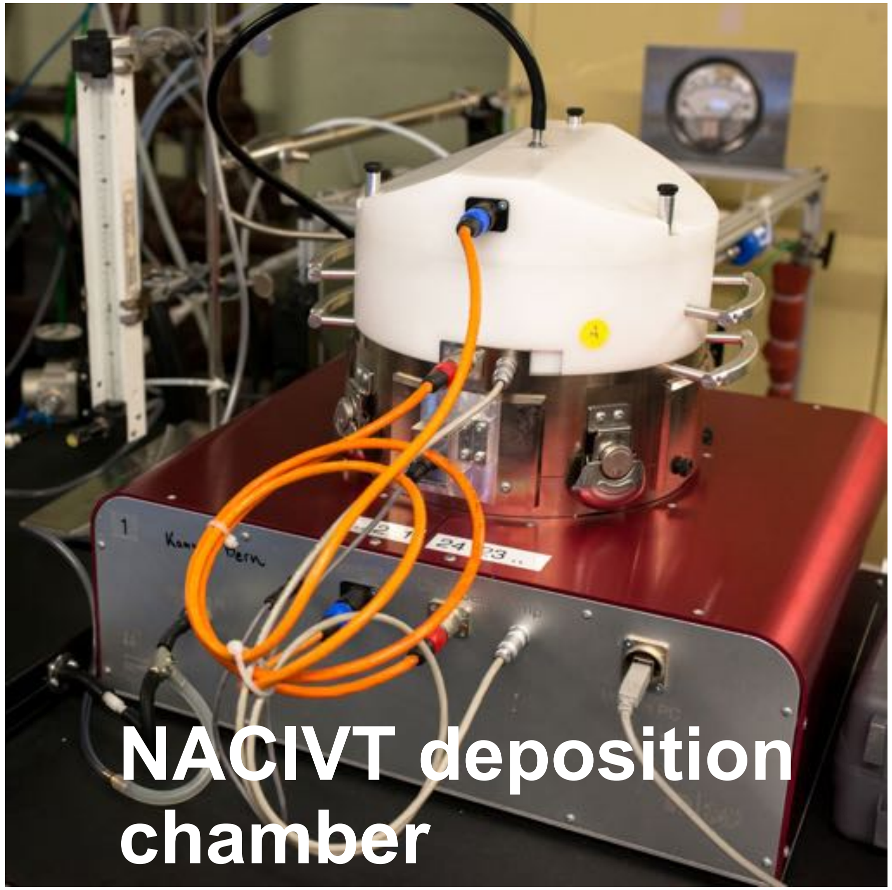
## Sampling and Measurement System "SMARTEMIS" – Swiss Mobile Aircraft Engine Emissions Measurement System




- NACIVT – Nano Aerosol Chamber for In-Vitro Toxicity https://www.nacivt.ch/
  - Sampling time 60 minutes including particle-free exposure at each test point
  - Thermodenuder upstream of the chamber for volatiles removal (just a precaution, volatile fraction minimal in exit plane sampling)
  - Deposition veririfed by electrometer measurements in the chamber

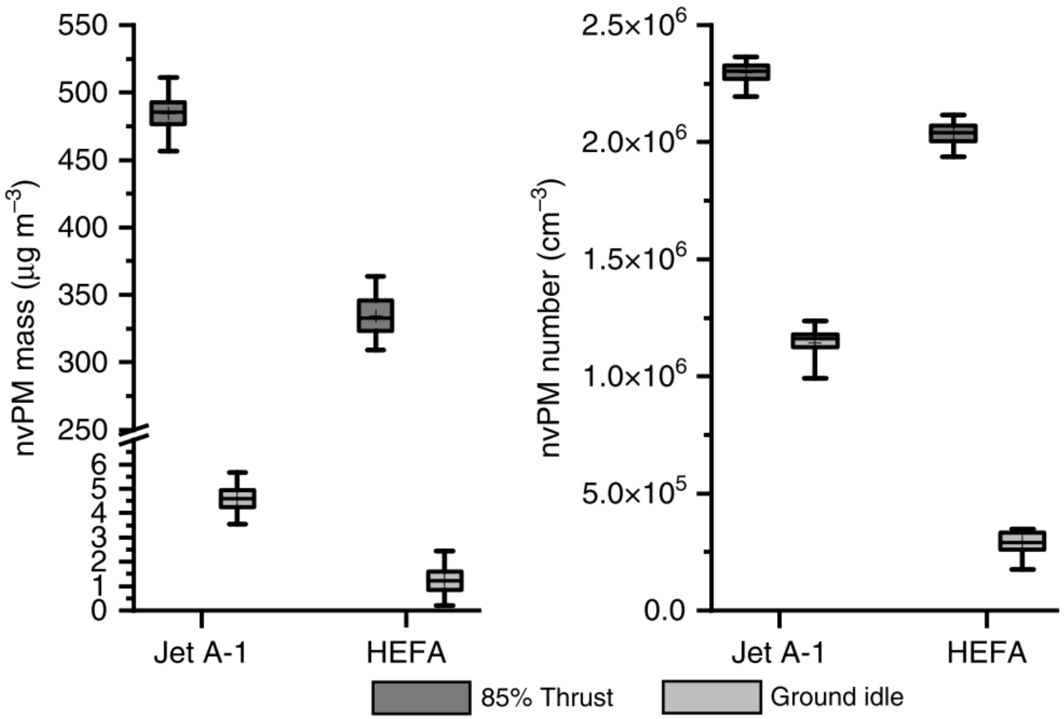
# Sampling and Measurement System “SMARTEMIS” – Swiss Mobile Aircraft Engine Emissions Measurement System

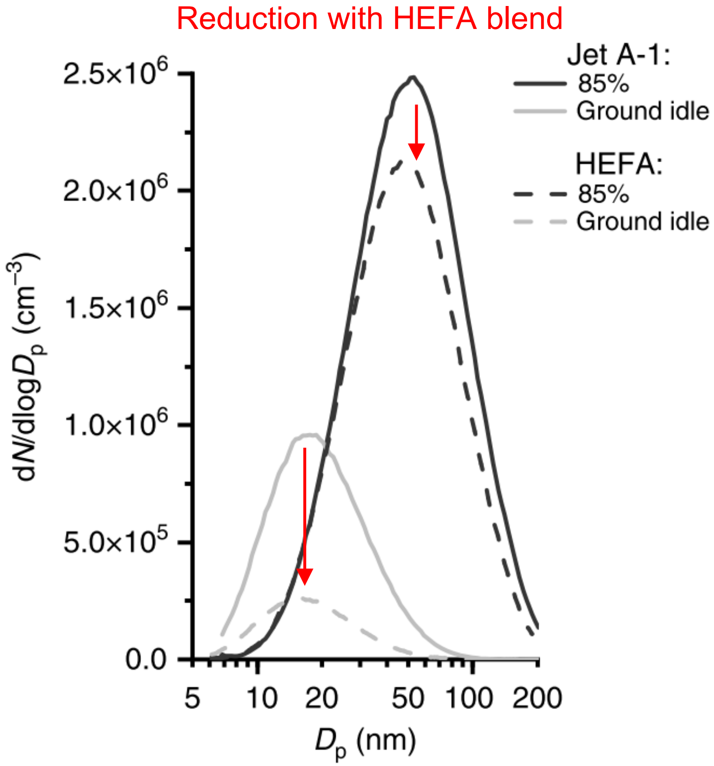


# nvPM particle size, morphology, and concentrations are highly thrust dependent

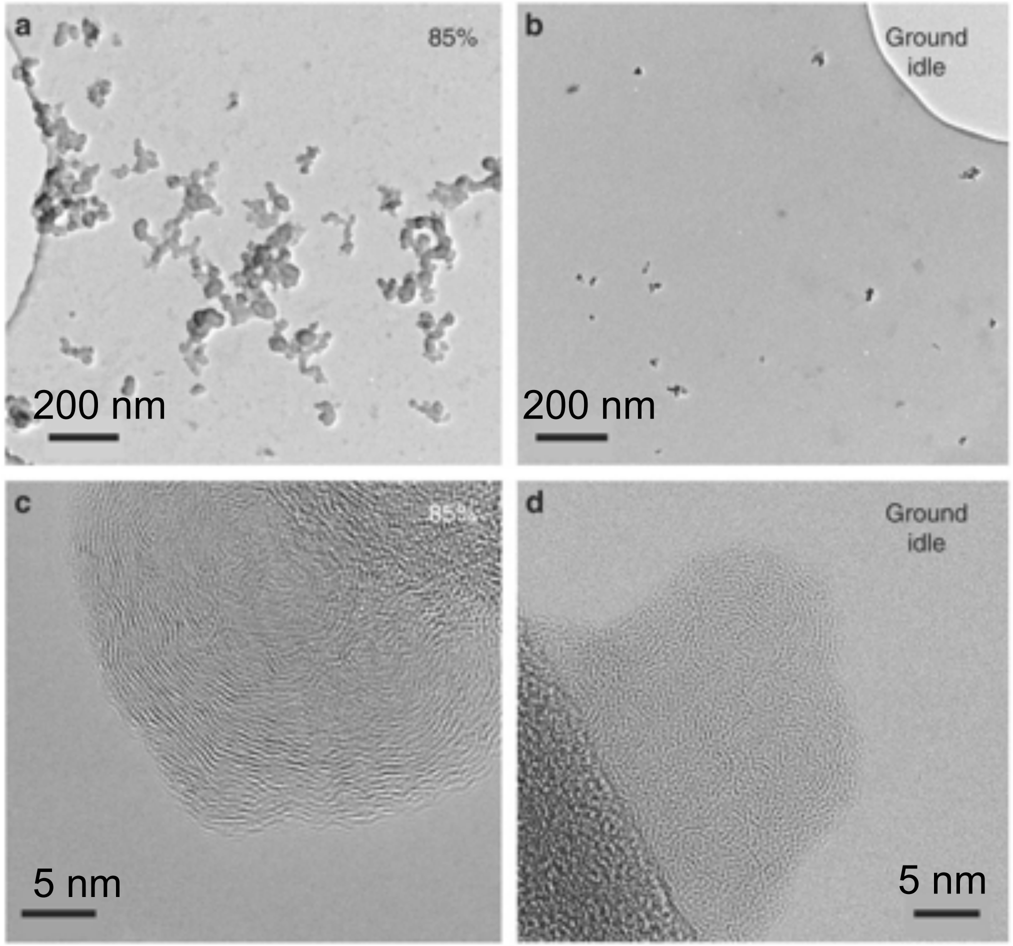
- Higher doses of nvPM at 85% thrust than at idle
- Higher relative nvPM reduction with the HEFA blend at idle



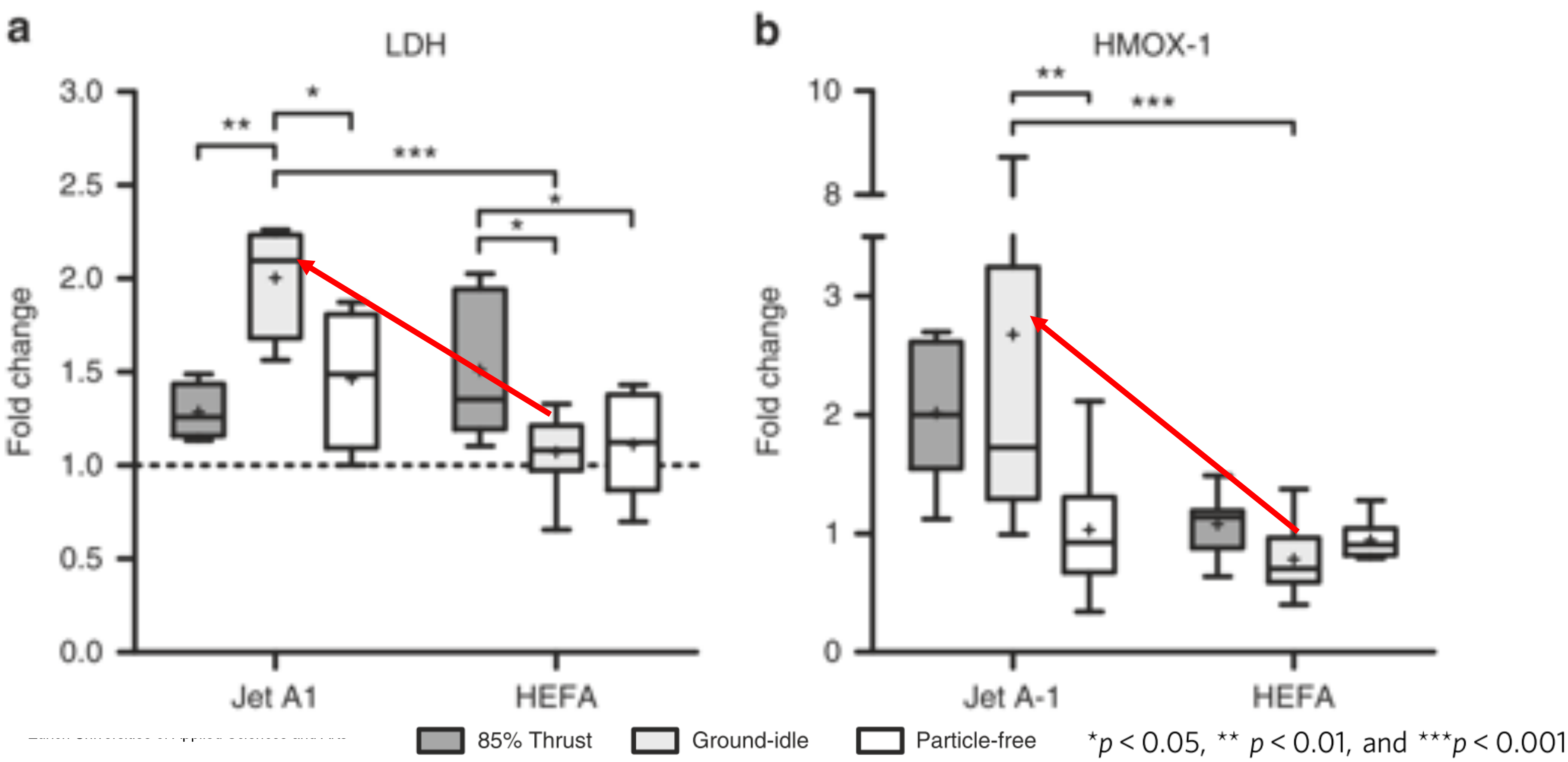
# TEM images show morphological differences between high thrust and idle

- Samples with HEFA blend (representative for both fuels)



# Acute cytotoxicity and oxidative stress highest at idle and with Jet A-1

- Biomarkers assessed 24h after exposure (acute cellular response)
- LDH = lactate dehydrogenase; acute cytotoxicity marker
- HMOX-1 = heme oxygenase 1; oxidative stress marker




*$p < 0.05$, ** $p < 0.01$, and ***$p < 0.001$

# Conclusions

- nvPM from Jet A-1 at idle caused highest cytotoxicity and oxidative stress
- Number and mass concentrations seem not to be the primary drivers of cytotoxicity and oxidative stress in this study
- nvPM from alternative fuel blends with lower aromatic content potentially less harmful

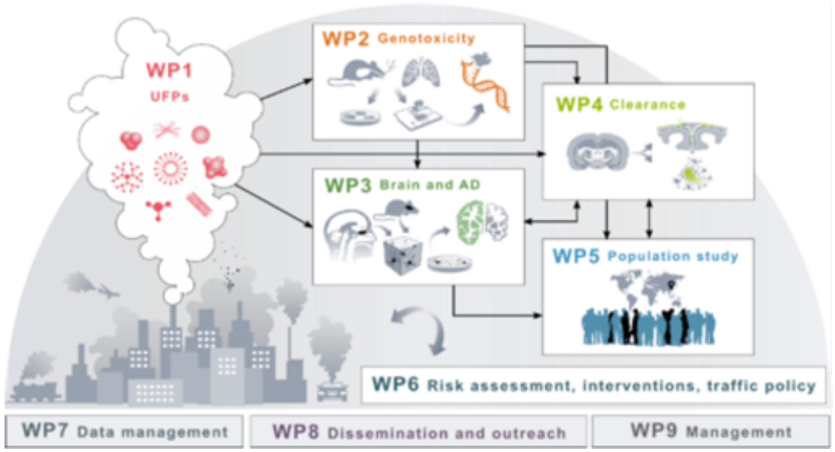
# Recommendations for future experiments

- Use of different cells
  - Primary airways cells
  - Disease human respiratory cells
- Volatile PM further downstream of the engine exit (organics, sulfates, oil)

# UFP workshop

15.9.2020

# TUBE aims



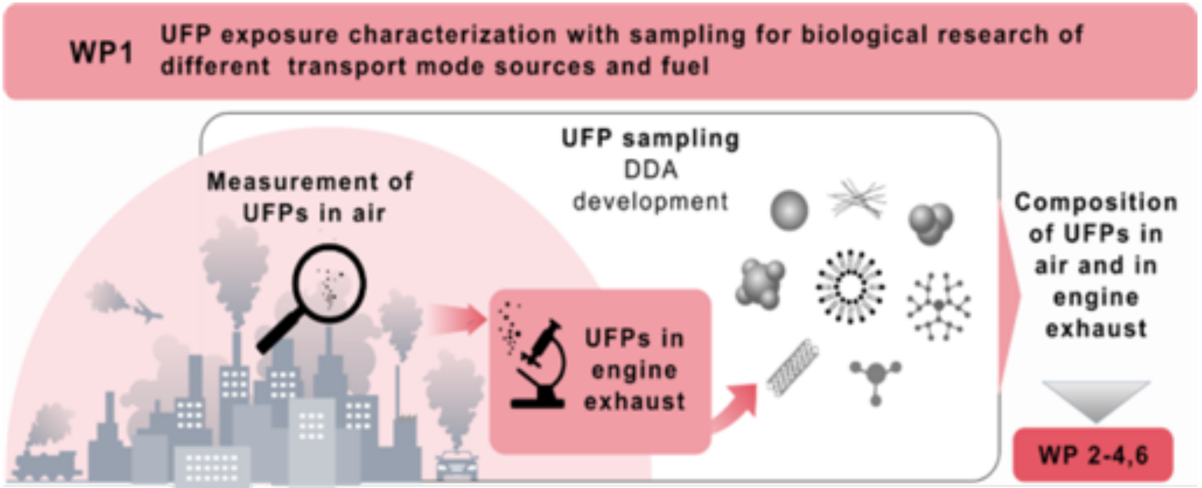

- Main focus on the effects of ultrafine particles from road traffic to brain health, including the disease mechanisms, translocation and clearance
- Respiratory toxicology and genotoxicity with online exposure systems
- Engine exhaust from cars, trucks/buses, marine engines as well as characterization of traffic environments
- Combining toxicological research in cells, mice and human to provide better tools for risk assessment
- Epidemiological data from Sweden and China to be combined with biomarkers in toxicological studies
- Electric bus intervention in Santiago CL to asses impact of fleet changes to air quality in highly polluted environment

# TUBE aims II

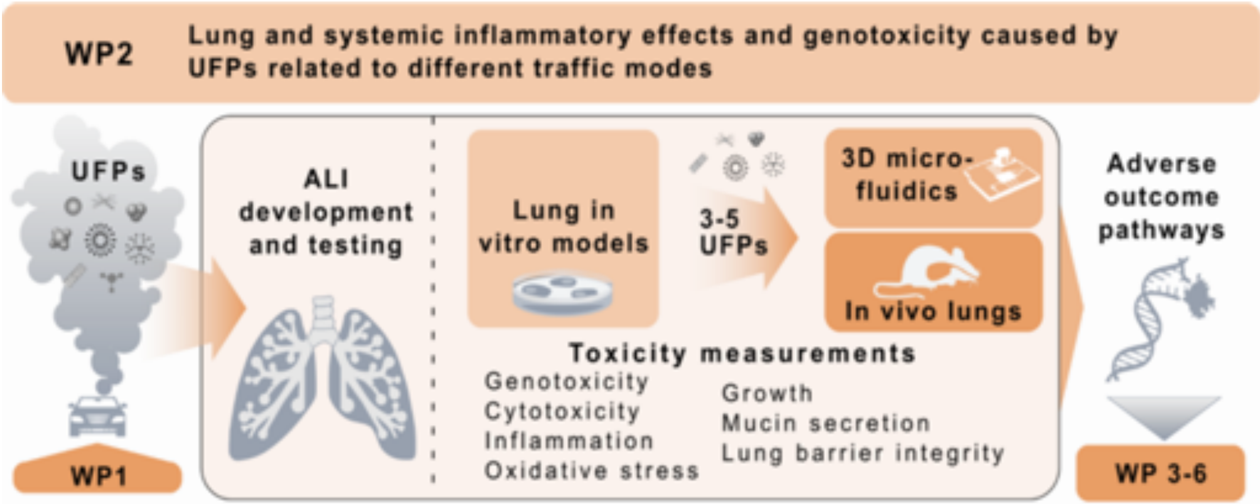
**The specific aims of the project are to:**

- Recognize which air pollutants from road traffic are responsible for the adverse health effects seen in humans, **emphasizing the detection and specific effect evaluation of the extremely fine UFPs**.
- Develop methods for detecting these particles directly from traffic.
- Use state of the art ***in vitro* and *in vivo* models to study the effects of transport-derived UFPs** and their bound constituents on **the respiratory system and brain.**
- Resolve how **UFPs from traffic affect brain health** in humans.
- Correlate the results from human experimental data with cell and animal experiments **and contribute to development of animal alternative testing developments (3R) for toxicity testing of air pollutants**.
- Correlate the findings of a cohort study in China with particulate chemical composition.
- Compare the laboratory results with a case study on reducing traffic related air pollution in Chile.
- Provide **mitigation strategies for emissions** of road traffic and non-road equipment.
- Perform data integration and **concomitant risk assessment**.
- Provide data that will be used to support **planning the future of the traffic policy**

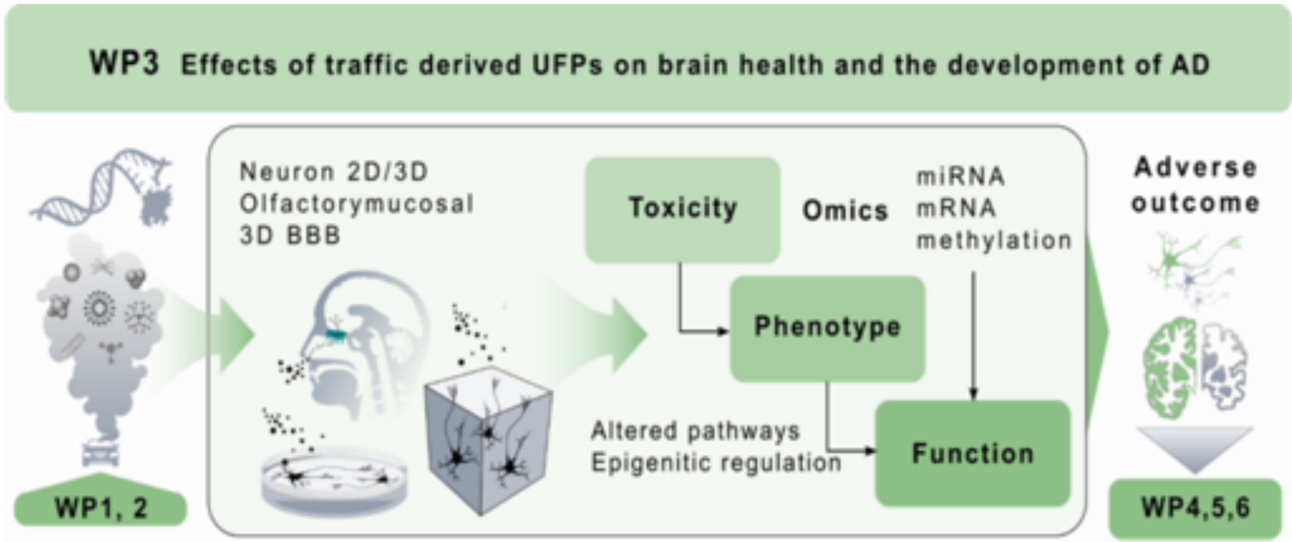
# TUBE structure



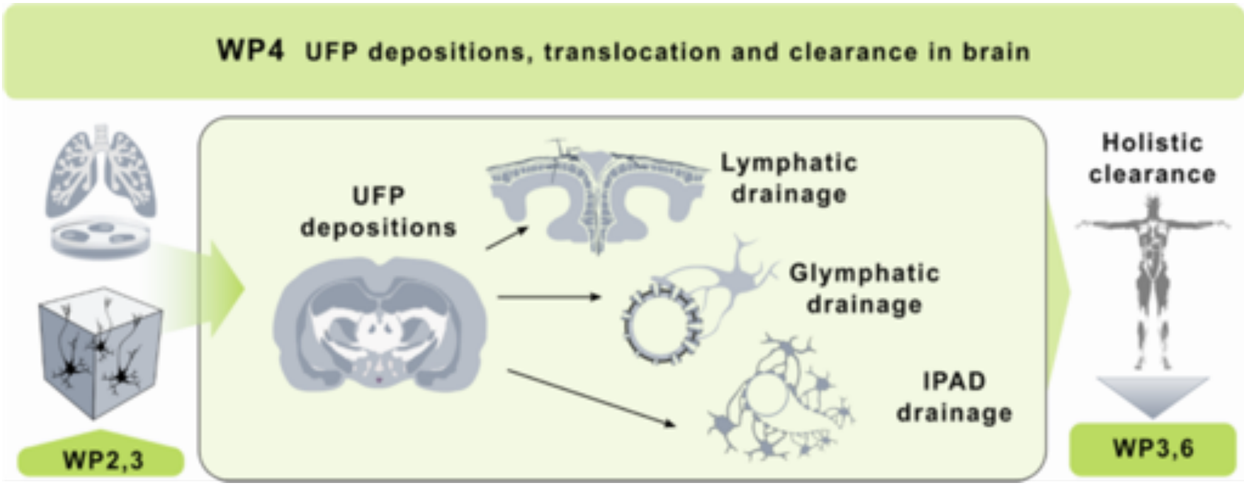

*- Development of the methods for nanoparticle sampling.*
*- Characteristics and concentrations of the UFP in environments influenced by different transport modes.*
*- Laboratory studies for the effect of fuel aromatics on the health-effects of exhaust.*
*- UFP in heavily polluted urban environments: Guangzhou and Santiago de Chile*
*(Sun Yat-sen University has received parallel national funding from China)*



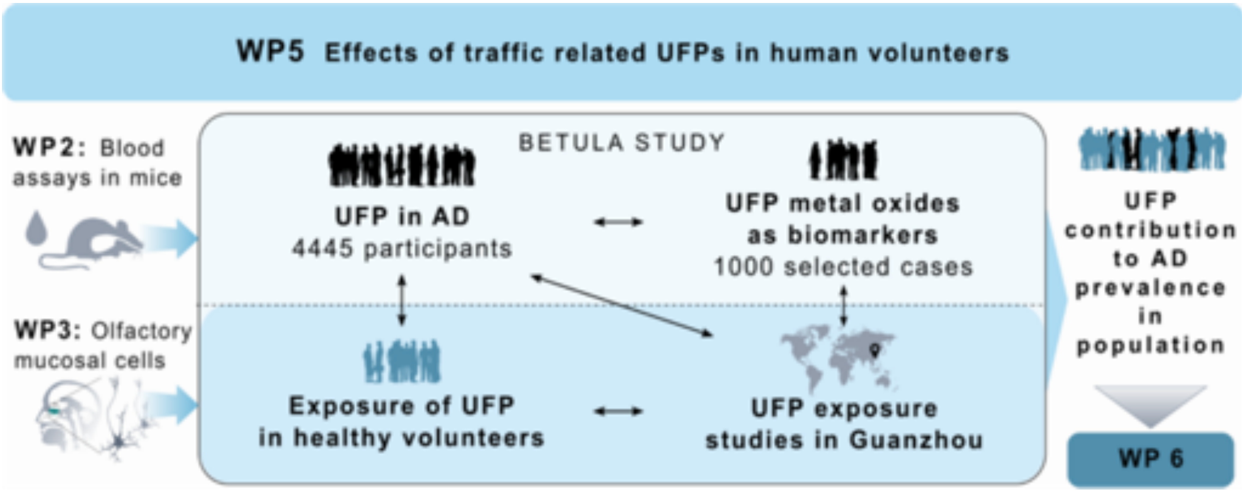

*- Development of methods for inhalation toxicology experiments using novel approaches*
*- In vitro inhalation toxicology experiments on the traffic related emissions in source-environment and laboratory*
*- In vivo approaches on the traffic related emissions*



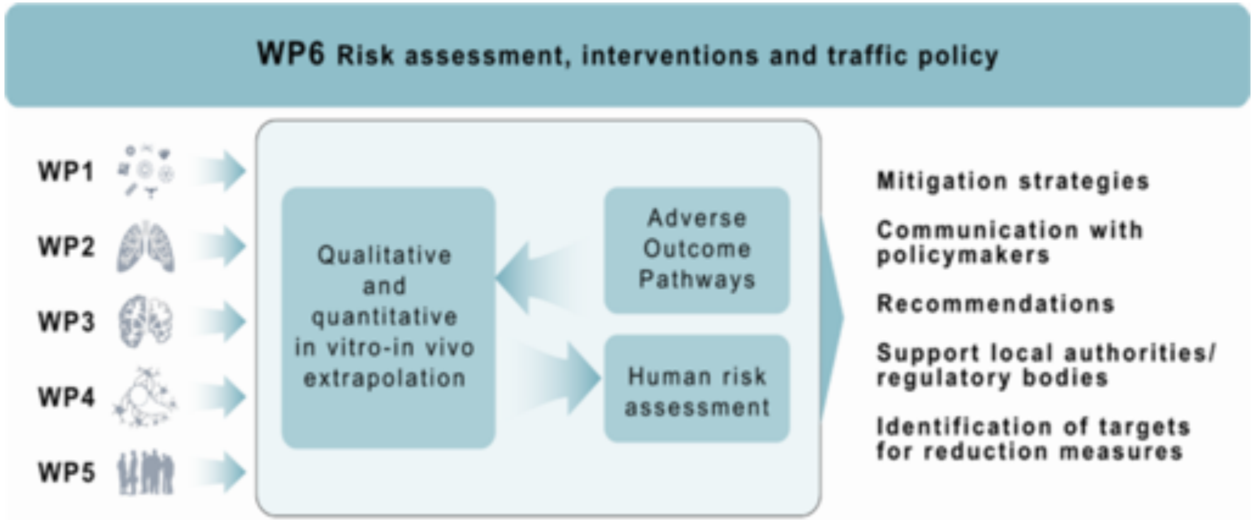

- *Identification of UFP effects in health (Novel cell based methods)*
- *Identification of UFP effects in disease (AD)*




- **Evaluation of dural lymphatics on UFP clearance**
- **Evaluation of UFP clearance through IPAD**
- **Impact and clearance of UFPs through glymphatics**




- Evaluation of UFP exposure on the risk of developing AD (epidemiological studies).
- Evaluation of UFP exposure on olfactory system function (experimental studies).
- Evaluation of levels of metal oxides in the AD patient blood (laboratory studies)




- **Establishing quantitative *in vitro* - *in vivo* extrapolation**
- **Human risk assessment**
- **Development of Adverse outcome pathways**
- **Advice on mitigation strategies**

# Samples

Collected particles mainly from VTT

For direct exposures samples have to be produced locally (ALI/inhalation)

| Emission | Fuel | After-treatment | WP1 Chem. & phys. analyses, oxidative potential | WP2 Lung inflammation | | WP2 Geno-toxicity | WP3 Neuro-toxicity in vitro | | WP3 AD phenotype | WP3 Neuro-inflammation | WP4 Deposition & localization in brain | WP4 Clearance from brain | WP5 Human exposures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | many methods, DTT assay | Sub-merged | ALI | Mouse | Human | Mouse | | | | | |
| **VSP Model Particles** | 1-10 nm particles | | x | x | x | x | x | x | x | x | x | x | |
| **Marine engine** | Distillate fuel | N | x | x | | x | x | x | | | | | |
| **Heavy-Duty Diesel (Bus/Truck)** | Low A | Y | x | x | x | x | x | x | x | x | x | x | x |
| | High A | Y | x | x | x | x | x | x | x | x | x | x | x |
| **Non-Road Diesel, Heavy-Duty** | Low A | Y | x | x | x | x | | | | | | | |
| | High A | Y | x | x | x | x | | | | | | | |
| **Diesel Car** | Low A | Y | x | x | x | x | | | | | | | |
| | High A | Y | x | | | | | | | | | | |
| **Gasoline Car** | Low A | Y | x | x | x | x | | | | | | | |
| | High A | Y | x | | | | | | | | | | |
| **Diesel/Gasoline Car at low test T (-7°C)** | Low A | Y | x | x | | | | | | | | | |
| | High A | Y | x | x | x | x | | | | | | | |
| **Aging of the Emissions** | | | x | x | x | x | | | | | | | |
| **SVOC emissions** | | | x | x | x | x | | | | | | | |

A = Aromatic; T = temperature; Y = Yes; N = No;

# TUBE progress so far

- UFP samples collected at VTT for cell and animal experiments
- Sample collections will continue
- Starting campaign with engine exhaust and ALI system
- First aerosol measurement campaign done, next ones had to be canceled due to COVID
- Optimization of the cell models are ready and various experiments
- We have had delay in the composing the sample matrix, but the work is on-going

# Near future objectives

- To complement the sample matrix
- Start all the biological experiments of the project
- Some of the animal experiments will follow later
- To finalize the aerosol measurement field campaigns in severral locations

- The sample matrix could be complemented to be analyzed in more basic cell models (aviation, ship emissions)
- For very advanced neurological cell or animal models it is not currently economically feasible

National Research Centre for the Working Environment



# Health effects of airport emissions

Ulla Vogel
Professor NRCWE
Adjunct professor, DTU Health Tech
European Registered Toxicologist

DTU

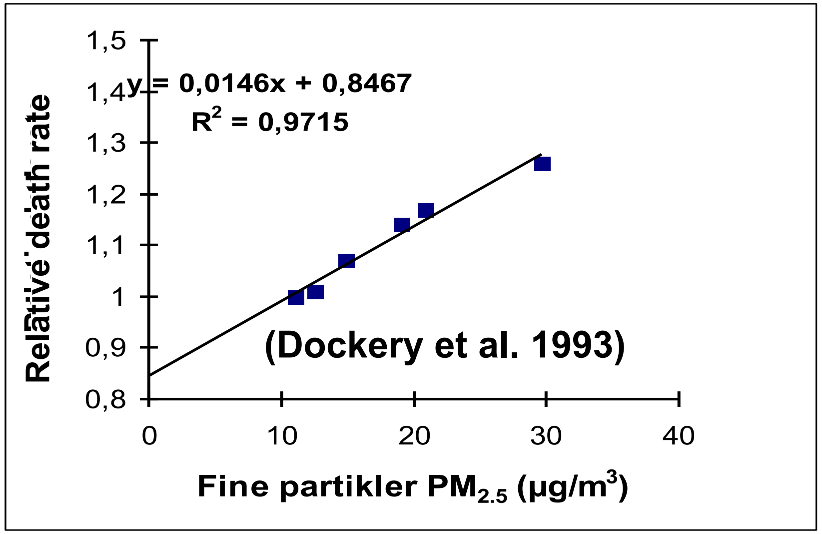
# Nanosafety at the National Research Centre for the Working Environment, Copenhagen, Denmark

- Government research institute under the Ministry of Employment
- Nanosafety as strategic research area 2005-2019
- At present ca. 35 persons in research in chemical working environment
- Advisors for the Danish Working Environment Authorities, EPA, EU, OECD, WHO
- Past and present partners in more than 30 EU projects on (nano)particle safety

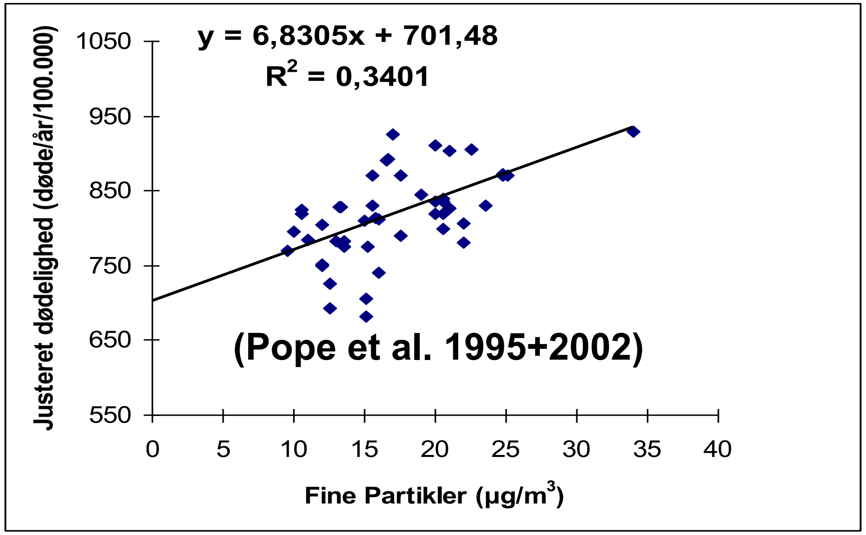
National Research Centre for the Working Environment

# Concern: Association between particulate air pollution and mortality

6 cities with 8000 people




151 urban areas with 500.000 people




Direct correlation between mortality and particle concentration ($PM_{2.5}$):

7 deaths/100 000 persons/year/ ug/m³ PM 2.5

National Research Centre for the Working Environment

# Evaluation of cancer risk by IARC (WHO’s research institute for carcinogens)

- Almost all current aviation fuel/jet fuels are extracted from the middle distillates of crude oil (kerosene fraction), which is in between the fractions used for gasoline and diesel

- Diesel engine exhaust is classified as carcinogenic to humans (class 1) by IARC
- Gasoline engine exhaust is classified as possibly carcinogenic to humans (class 2B) by IARC
- Carbon black (pure carbon particles) is classified as possibly carcinogenic to humans (class 2B)

# Risk estimate for DEP based on epidemiological evidence

**Table 1.** Exposure–response estimates (lnRR for a 1-μg/m³ increase in EC) from individual studies and the primary combined estimate based on a log-linear model.

| Model[a] | Intercept | β (95% CI) |
|---|---|---|
| All studies combined | 0.088 | 0.00098 (0.00055, 0.00141) |
| Silverman et al. (2012) only | –0.18 | 0.0012 (0.00053, 0.00187) |
| Steenland et al. (1998) only | –0.032 | 0.00096 (0.00033, 0.00159) |
| Garshick et al. (2012) only | 0.24 | 0.00061 (–0.00088, 0.00210) |

[a]Log-linear risk model (lnRR = intercept + β × exposure). Exposure defined as EC in μg/m³-years.

**Table 2.** Excess lifetime risk per 10,000 for several exposure levels and settings, United States in 2009.

| Exposure setting | Average EC exposure (μg/m³) | Excess lifetime risk through age 80 years (per 10,000) |
|---|---|---|
| Worker exposed, age 20–65 years | 25 | 689 |
| Worker exposed, age 20–65 years | 10 | 200 |
| Worker exposed, age 20–65 years | 1 | 17 |
| General public, age 5–80 years | 0.8 | 21 |

Based on linear risk function, lnRR = 0.00098 × exposure, assuming a 5-year lag, using age-specific (5-year categories) all cause and lung cancer mortality rates from the United States in 2009 as referent.

The new EU OEL for DEP is 50 ug/m³

Vermeulen et al, EHP, 2014

New meta-analysis of case-cohort studies using JEM for exposure assessment:
Excess life time risks associated with 45 years of EC exposure at 50, 20, and 1 μg/m³ were 3:100, 1:100, and, 4:10 000, respectively, (PMID: 32330395, April 2020)

National Research Centre for the Working Environment

# NRCWE study

- Work place exposure assessment at a non-commercial airfield with jet fighters
- Particle collection and characterisation of particles from a large commercial airport and a non-commercial airfield
- Animal study where mice were exposed to collected particles in the lungs alongside standard NIST diesel exhaust particles and carbon nanoparticles
- Published open access 2019


Bendtsen et al. Particle and Fibre Toxicology (2019) 16:23
https://doi.org/10.1186/s12989-019-0305-5
Particle and Fibre Toxicology

RESEARCH Open Access

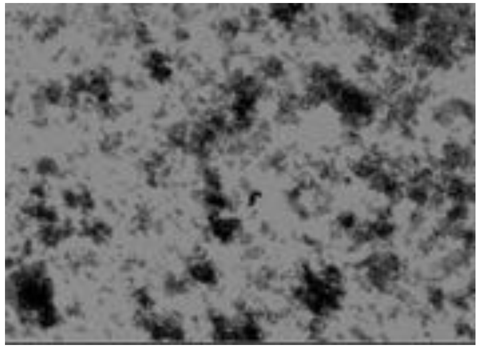
Airport emission particles: exposure characterization and toxicity following intratracheal instillation in mice

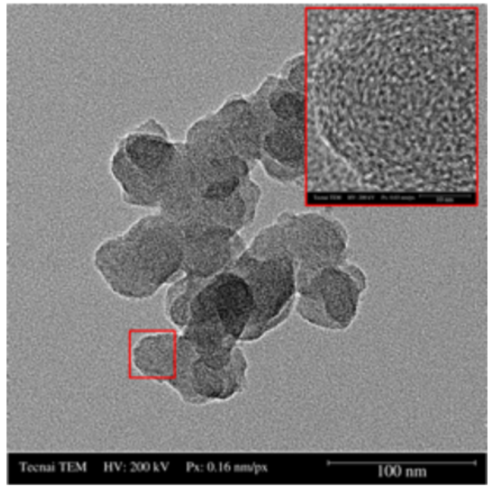
Katja Maria Bendtsen[1], Anders Brostrøm[1,2], Antti Joonas Koivisto[1], Ismo Koponen[1,3], Trine Berthing[1], Nicolas Bertram[1], Kirsten Inga Kling[2], Miikka Dal Maso[4], Oskari Kangasniemi[4], Mikko Poikkimäki[4], Katrin Loeschner[5], Per Axel Clausen[1], Henrik Wolff[6], Keld Alstrup Jensen[1], Anne Thoustrup Saber[1] and Ulla Vogel[1,7*]

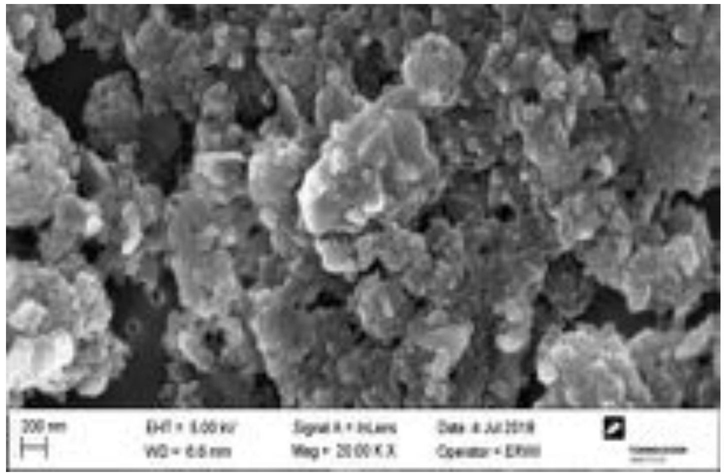
# Jet engine emission particles

- Aircraft engines emit large amounts of nanosized carbon-based particles
- Primary particle size ca. 15 nm (smaller than DEP)
- Aggregates in air
- PAH content similar to standard NIST DEPs
- Metal content similar to standard NIST DEP

- Airport emissions from the commercial airport were much more complex and contained salt crystals, organic particles ect in addition to the small soot particles






EM picture of jet fighter emissions during taxi (from a chasing car)

# Exposure levels for the Crew Cheif at the non-commercial airfield

**Table 2** Average exposures and doses of jetfighter personnel at a non-commercial airfield

| Event | $t$, [min] | $n$, ×10$^6$ [cm$^{-3}$] | $m$, [µg m$^{-3}$] | $m_{PM4}$ [µg m$^{-3}$] | $DR_N$ × 10$^{10}$ [min$^{-1}$] | HA, n[%] | TB, n[%] | AL, n[%] | $DR_m$ [µg min$^{-1}$] | HA, m[%] | TB, m[%] | AL, m[%] | Particles [× 10$^{12}$]/ Event | Mass [µg]/ Event |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PL | 15.1 | 7.7 | 1086 | 537 | 15 | 21.2 | 27.2 | 51.6 | 18.7 | 84.6 | 4.7 | 10.7 | 2.26 | 280 |
| PA + FT | 21.3 | 2.67 | 410 | 228 | 5.4 | 21.7 | 27.7 | 50.7 | 7 | 83.6 | 4.9 | 11.5 | 1.15 | 150 |
| $t_{FS44}$ | 170 | 1.22 | 194 | 89 | 2.4 | 21.4 | 27.4 | 51.3 | 3.5 | 85.8 | 4.6 | 9.6 | 4.12 | 600 |

Average exposures and doses during Plane Leaving (PL), Plane Arrival and fueling the plane (PA + FT combined), and over one flight cycle ($t_{FS44}$). From left to right: average event time ($t$) in minutes, average particle number concentration ($n$), mass concentration ($m$) and mass fraction smaller than 4 µm ($m_{PM4}$), inhaled number dose per minute ($DR_N$), predicted fraction of particles deposited in extra-thoracic (HA), tracheo-bronchial (TB) and alveolar (AL) lung regions, inhaled mass dose per minute ($DRm$), predicted fraction of mass deposited in extra-thoracic (HA), tracheo-bronchial (TB) and alveolar (AL) lung regions, total particles per event and total mass per event

Exposure levels in a jet engine test facility: 2-4 x 10$^6$ particles/cm$^3$ (data in supplementary)

# Animal study of health effects following lung exposure to airport emission partilcles

- Animal studies are used to establish causal relationships, which is difficult in epidemiological studies
- Mice were exposed to JEP (jet emission particles) and CAP (Commercial airport particles) by pulmonary instillation at 3 dose levels and followed for 1, 28 and 90 days
- Endpoints:
  - Lung histology (Biopersistence and histological changes)
  - Lung inflammation (biomarker of toxicity)
  - Acute phase response (biomarker for risk of cardiovascular disease)
  - DNA damage in lung, lung fluid cells, liver (biomarker for risk of cancer)

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# Two different airport emission particles cause the same health effects in mice as standard NIST diesel exhaust particles and carbon nanoparticles

- The two airport emission particles induce the same health effects in mice as two NIST standard diesel exhaust particles including:
  - inflammation (general toxicity marker),
  - acute phase response (biomarker of cardiovascular risk)
  - DNA damage (biomarker of cancer risk)
  - No histological changes were observed

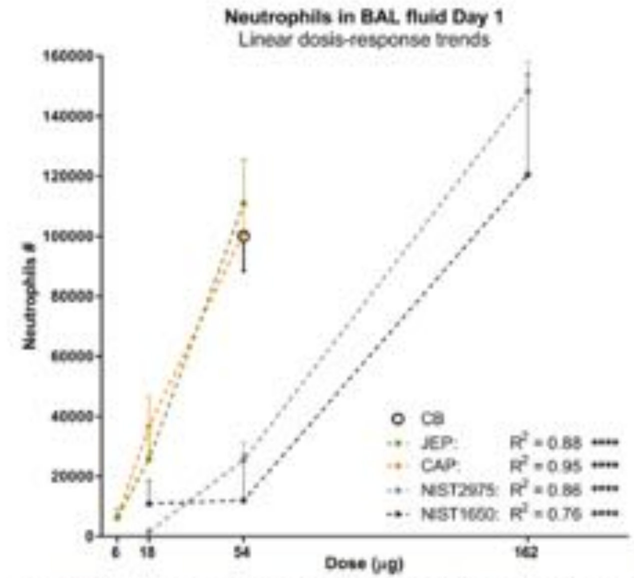


**Fig. 4** Illustration of dose-response linearity between instilled doses of airport-collected particles, NIST2975, NIST1650 and neutrophil influx in BAL. Increasing dose-response effects were confirmed with test for linear trend, where the alerting R2 (referred to as R2) is the fraction of the variance between group means that is accounted for by the linear trend (Altman/Sheskin, provided by GraphPad Prism). Data for NIST1650 was obtained from a previously published study [19]. Significant linear trends were verified for total cell numbers (not shown) and neutrophils in BAL fluid, with R2 between 0.76 and 0.95

# Summary

- Aircraft emission particles have similar physico-chemcial properties as diesel exhaust particles and carbon nanopariticles
- Aircraft emission particles have similar health effects as diesel exhaust particles and carbon nanoparticles in mice including increased inflammation and biomarkers of risk of cardiovascular disease and cancer
- The study suggests that aircraft engine emission particles and airport emissions have similar health effects as diesel exhaust particles and other traffic related emissions

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# Thank you for your attention

The study was part of Danish Centre for Nanosafety 2